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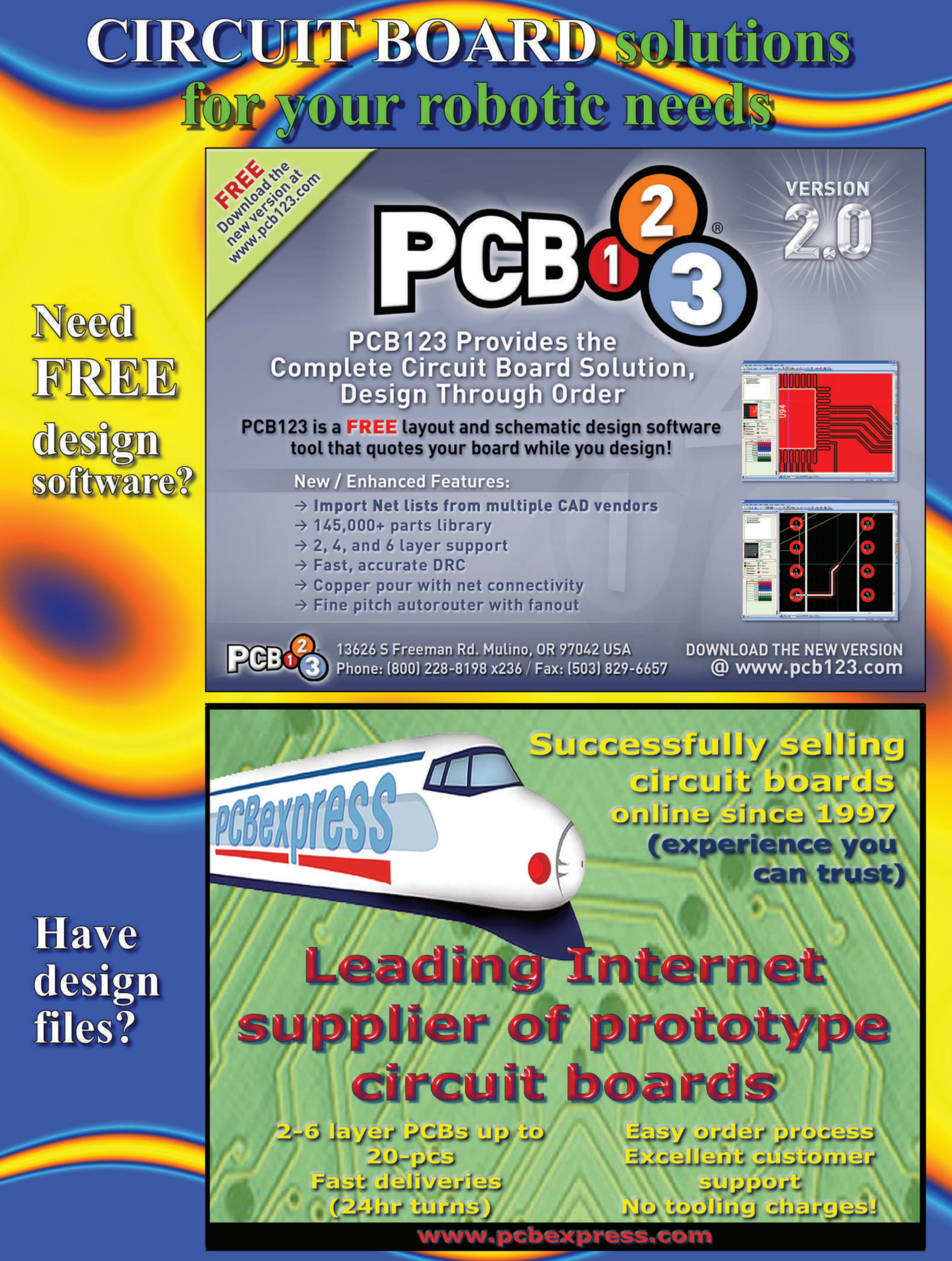
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SERVO

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Coming

07.2004

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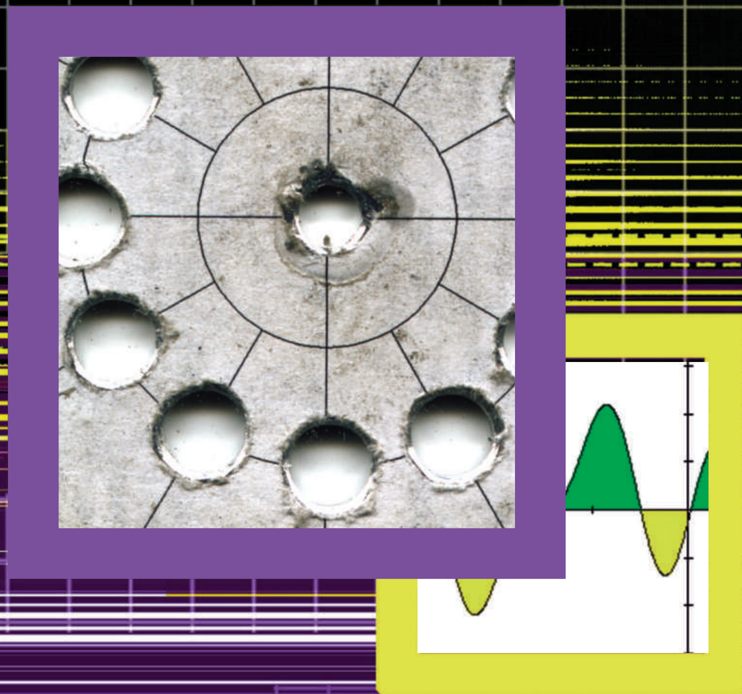

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Mind / Iron

by Dan Danknick

Before I came to work here at *SERVO Magazine*, I wrote communications firmware. All in all, it was a largely objective job — given a $9.00 CPU with limited RAM and ROM, there is generally an agreed upon "best" way to do something. So, when I had finished coding up routines based on the manufacturer's data sheets, I was sure it was correct.

Working for a magazine is a completely different ball game. As the technical editor, I'm responsible not only for the correctness of all non-advertising content, but for the selection of it, as well. The latter, in contrast, is largely a *subjective* job. The words of economist (and personal hero) Peter Drucker frequently float into my mind, "Management is doing things right; leadership is doing the right things."

I get a lot of Email telling me that I'm doing the right things and a fair amount telling me that I'm not. Which should I believe? The answer is easy: both — if they understand the vision I have for the magazine. I hope this doesn't sound like some *11 Habits of Highly Effective, Prime-Numbered People* spiel because I'm not an adherent of that stuff. I am, however, focused on a goal in my role with this organization.

As for that, I think back to a book that changed my life when I was a kid. It was by Forrest M. Mimms (another personal hero) and it was called *The Engineer's Notebook*. I bought it on a whim at RadioShack when I went in to utilize my "Free Battery Club Card" (remember those?) sometime around 1980.

Mimms' book taught me a lot about digital and analog circuits, but it also taught me about how to teach people about digital and analog circuits. If I could distill a "hit list" from his book, it would be:

- Explain the basics.
- Demonstrate a cool project that either blinks or makes noise.
- Suggest ways for the experimenter to expand upon the design.

This is the approach I take to the editorial construction of *SERVO*.

Are there too many articles on basic robotic constructs? No, because many readers are just getting into the groove with robotics and they need these things explained. Are there too many advanced articles on complex software algorithms or analog circuits? No, because other readers want something to chew on to stimulate their minds. The goal of both types of articles should lead to an ultimate action on the part of the reader: that of picking up some material and fashioning a new device. That's the vision I have for the magazine — to promote and facilitate action.

The *details* of this vision depend largely upon you, the reader. My Email address is published to the right of this column in every issue and I encourage you to share your thoughts — positive and negative — with me. If you want them to be private, just say so.

This communication is important, as the other part of my vision for *SERVO* is to see it grow in size and scope; that depends directly on your satisfaction, which reminds me of another quote by Drucker, "The purpose of business is to create and keep a customer." SV

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OUR PET ROBOTS
Guido
Mifune

BIO-FEEDBACK

Dear SERVO:

The cover teaser on the April issue, "Testing Robots in Antarctica" was more than a little misleading. On first getting that issue, I hunted through it twice ... and finally spotted a similar photo of Dr. Behar (not the one on the cover!) in an article about planetary exploration. Nary a word about Antarctica. Come on, don't the folks who do the cover know what the content of the issue will be?

You could help steer the reader to these features by putting a page number beside the feature blurb, especially since you don't like to use the actual title (or even the actual subject!) of the feature article:

"Student Built LEGO Robots," p. 14
"Testing Robots in Antarctica," p. 9
"Building for Tetsujin," p. whatever.

My favorite article was "Measuring Dust on the Red Planet: Muscle Wires on Mars," by Roger Gilbertson. My favorite column is "Cutting Edge," the on-going multifunction robot by John Myszkowski.

Keep 'em coming!

T. Gray
via Internet

Please find my reply to your suggestion on page 9. — Editor Dan

Robotic Life is a ... Beach? Editor Dan — working as a volunteer judge for the sixth year — was surprised to discover FIRST Team 294 handing out copies of *SERVO Magazine* at the Los Angeles, CA regional competition in April. Their commitment to the program went on to earn them the Regional Chairman's Award for their impact on the local community — a high achievement. Way to go, 294!

Dear SERVO:

I'm writing in regard to the Hexatron robot plans you featured in your November 2003 edition. First of all, I realize that none of this is your problem or your fault, but I'm hoping you can help.

I'm new to robotics, but very excited about it. I decided to build the Hexatron robot — my first non-toy robot project. For about two months now, I've been trying everything I know to find the parts for it. This includes Emailing the author and many other people. Though I've had to go to dozens — if not hundreds — of sites, I've found all the parts, except the 4.55K potentiometer.

Would you have any idea where I might find this part? I thought I had it at **www.Stampbuilder.com**, but the author couldn't help me there, either.

The problems I have been going through to find these parts are very disheartening. I can't help but wonder how many people who are new to the robotics hobby have turned away due to such problems. I'm tempted to start my own robotics supply business after this experience, but I can't even do that until I find a source for the remaining part I need.

The author of the article — Karl Williams — did a fabulous job on the instructions and pictures. It's a shame that he did not give enough information on the parts to allow novice hobbyists to build the robot.

For instance, there are dozens of variations of semiconductors that have "2N4403 PNP general purpose" as part of the description.

Thanks for reading my gripes. If I can just find this last part, I'm sure the project will be a blast.

Richard Alexander
Broken Arrow, OK

Any potentiometer in the 4.7K to 10K range will work. In addition, I've asked Mr. Roboto to cover the topic of substituting parts in an upcoming column. — Editor Dan

Continued on Page 79

got bot?

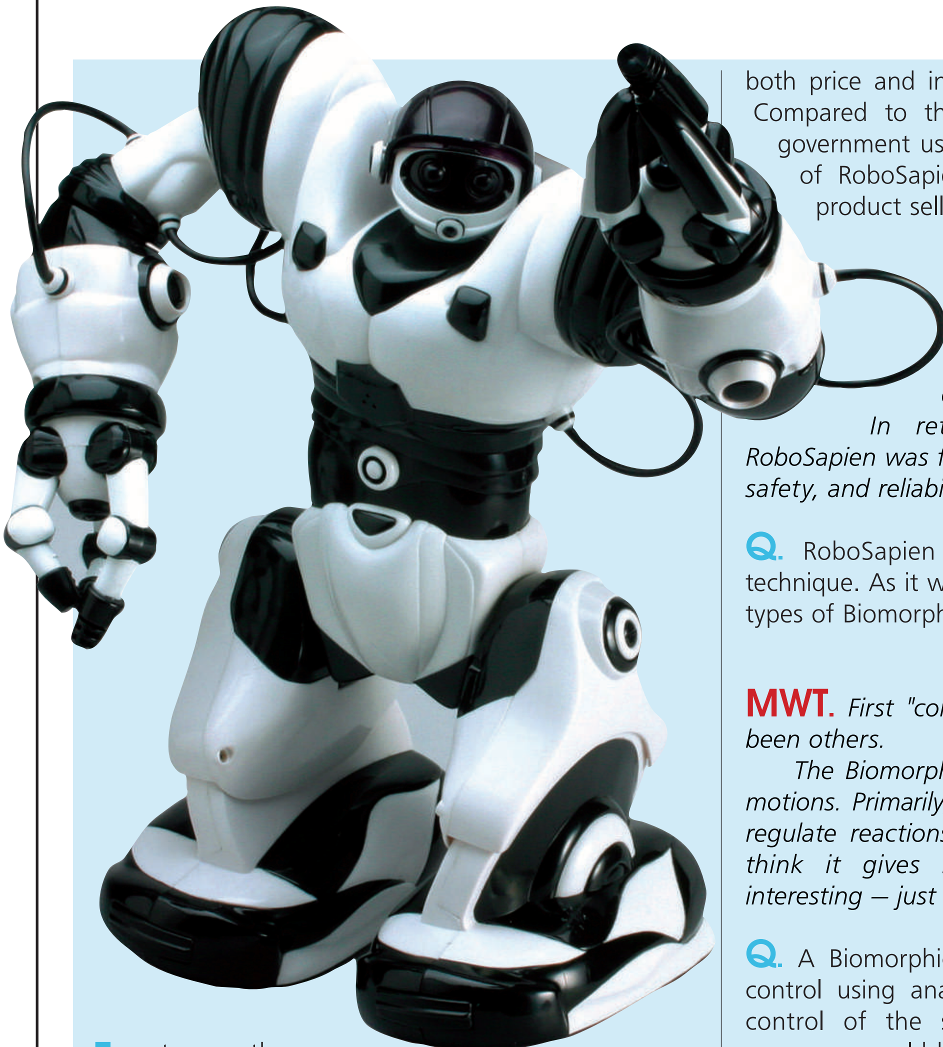
Whether you have a build, code, or theory to share, *SERVO* wants to know what you — the resident of the robot workshop — are creating. We want you to Email us your article submissions. Some topics of interest are:

- Sensors and signal processing
- Unique drive geometries
- Mechanical fabrication
- Material selection and use
- Software techniques
- Distributed communication
- Data protocols

Announcing Our New Area Code

As of July 17, our area code will change from (909) to (951). This will affect both our phone and fax numbers.

Mind of the Machine



Last month, you may have read the first part of this article about the inner workings of RoboSapien. The article included my notes on a full disassembly, covering mechanical details, processors, gripper design, and one of the best secret features — a reprogrammable reflex design. This built-in ability lets you completely change the robot's default reactions in about two minutes flat, like the autonomous walking program printed in last month's issue or any of the programs at **www.RoboSapienOnline.com**

There's more than that in store this month, as the creator of RoboSapien — Mark W. Tilden — discusses the design philosophies inside the machine and the choices made while creating an affordable Humanoid Robot. Here's my interview with Mark about creating mechanical minion that sells for $99.00 and has a unique blend of form and function, built on a remarkable foundation.

Q. RoboSapien really represents a breakthrough in both price and internal design of a consumer robot. Compared to the other robots you've created for government use, how challenging was the creation of RoboSapien — from design to a completed product selling under $100.00?

MWT. *Research centers will pay you $1,000,000.00 to produce one robot; in toys, it's the other way around. Other differences are equally extreme.*

In retrospect, though, designing the RoboSapien was fun and easy. Production, promotion, safety, and reliability — that was hard.

Q. RoboSapien was created using a Biomorphic technique. As it was your first humanform robot, what types of Biomorphic elements did you include?

MWT. *First "commercial" humanform — there have been others.*

The Biomorphic elements are in his gestures and motions. Primarily, they're there to improve efficiency, regulate reactions, and smooth motion. That others think it gives him human-like characteristics is interesting — just a side benefit of the efficiency.

Q. A Biomorphic approach is a method of robotic control using analog circuits. How does the analog control of the servos in RoboSapien differ from ways you would have had to implement control using digital-only feedback?

MWT. *Most robotics use "Setpoint Feedback," where a motor fights to match a set sensor value. My technique uses "Dynamic FeedThrough," where the motor is its own measure. This is difficult, as it can go chaotic at the drop of a hat, but, over the years, I've managed ways to get useful work out of it.*

Q. How do the springs at different joints aid the robot's motion — for instance, the springs in each leg?

MWT. The *same way as they do in a car: suspension. Many fine things are based on springs. Ask a mattress.*

Q. Is the Nervous net in RoboSapien named for similarities to our own nervous system? How does feedback through the motors using this system work?

MWT. *Nervous nets were so named because they are*

RoboSapien — Part 2

by Nicholas Blye

the mathematical inverse of Neural nets. Neural nets (Nu) are parallel arrays of integrators; Nervous nets (Nv) are a series chain of differentiators. Whether they have any biological justification is a subject of much debate and bar fights (Hi, Terry).

In a basic Nv control "core" array, motor loads attenuate the driving pulses, resulting in forward-predicting, self-optimizing behavior in differential action loops. In the first analog Robosapien, this worked very well to set parameters for the later, mass-manufactured, digital versions. The current digital model doesn't take care of this as efficiently as it could, but compromises had to be made for production.

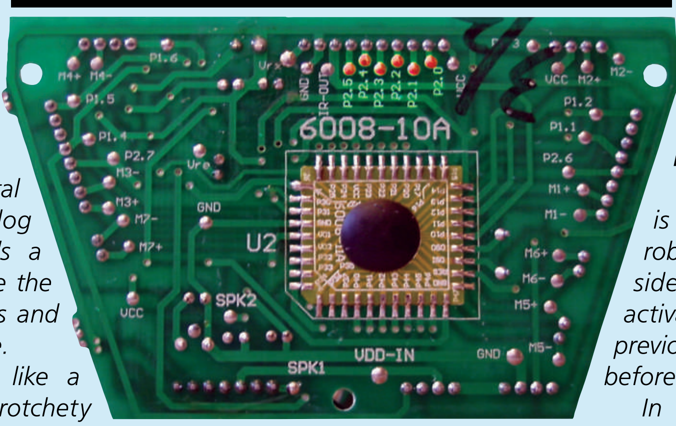
Q. Your focus creating robots before this one had been making analog-based robots that surpass the abilities of complicated, digital counterparts. What do you think are the limits of analog technology?

MWT. *Not much. To paraphrase an old saying, analog is as analog does. What I've found is that, in the same way you wouldn't want to design an analog word processor, why build a digital walker? Nature doesn't. Use the right tools for the right job.*

Analog is great for reflexes, adaptation, rhythm, somatic response, and action. It can get your bot where it has to go efficiently. What tasks it does when it gets there might require greater complexity. That's where digital shines, at least as far as robots go.

Q. Since the analog chip handles all the joint motions, how does the digital chip communicate commands? (For instance, when you play back one of the demo's — like dancing — does the digital chip send a "move joint, elbow, up 30 degrees" and monitor the motion or does it just send the command to move the joint, thus causing the analog chip to move the joint, monitor its position, and send a confirmation signal back when the motion is complete?

The analog chip on the controller board is "hackable" via the highlighted pins.



MWT. *Nope. The digital commands, the analog follows — unless there's a frustration, in which case the analog does what it likes and the digital can go whistle.*

The RoboSapien is like a digital cowboy riding a crotchety horse. Occasionally, the commands of the cowboy have to be ignored so the horse can steady itself.

Q. Are the demonstrations completely loaded into the firmware as canned actions or are there just commands to perform the motions, with the series of actions played back by the analog chip and under digital control?

MWT. *Both. I'm pleased to say that — with clever programming — one can recreate and rearrange the demos in the unit using the array of built-in actions, macros, and behaviors.*

Q. What's a good example of this flexibility?

MWT. *Try this with your RoboSapien: Make it walk from a smooth floor onto a throw rug. At the boundary, the digital still pumps out the same precise control signals, but the robot adjusts, adapts, and — more often than not — sorts it out. Digi-analog symbiosis in action — gotta have both.*

Q. Will a program to control the robot through external IR control let you control each joint individually to create your own actions or just use the commands supported on the remote?

MWT. The PC-RS control programs (now under development) take advantage of the robot's ability to respond faster to the remote than he does to his internal program, so the answer is ... maybe.

Q. How would you classify RoboSapien — as a robot, telepresence device, or something else? I'm curious where you feel it fits as a mechanical minion.

MWT. *All of the above. Here's why:*

RoboSapien Undocumented Autonomous Wandering Mode:

*If a reflex sensor (R or L) is *not* default, then the robot will blindly execute that side's reflex macro on activation, then *return* to the previous walking state it was in before the sensor touch.*

In this way, you can set the

robot up to autonomously wander about and, when it touches something either left or right, it can perform an action (push a box), then back up and turn away (or toward, if you like), then return to forward walking mode, with touch sensors at the ready.

He can follow program commands blindly, by conditional reactions (sound, touch), by sonic detection (which allows him to react to any hit on his shell), or through direct touch interaction. He's even set up so that, if you have two, one can be set as your puppet while the other, under program mode, waits for stimulus. You can set up entire acting scenes this way.

So, he's more a broad range, poly-featured, minimal, mechanical, multi-mode minion.

Q. When you refer to the robot as having a reflex, what kind of hardware and software define a reflex for RoboSapien?

MWT. *His three senses are left and right touch and sharp sonic. Reflexes are defined as a blind series of actions executed without sensor feedback. When he walks into something, normally, he just stops, but if the "reflex" is set on that side, he can perform real work on objects.*

Q. Is that a PIC processor onboard?

MWT. *Not really. It's just a very advanced sound processor with some PIC-like elements. Years ago — when I went through hell developing BIObug robot codes on simple sound sequencers — our chip vendors asked if there was anything I might want for the next IC generation. We spent a day discussing specs. The RS brain is the result. MIDI playback, 40 second quality sound, 12K firmware, four depth stack, advanced error handling, 40 I/Os, built-in magnitude comparators, stereo DAC outputs, 3.6 volt CMOS with microwatt standby power, four programmable counters, superior supply-line noise rejection, eight-bit advanced programming set with in-register Boolean and math functions (caveman grunts of appreciation: "ouah, ouah, Ouah, OUAH, OUAH!"). All at toy-grade prices.*

Q. Is Dolby 5.1 Surround Sound an option?

MWT. *Not unless you buy your bot an MP3 player.*

Q. How did you go about overcoming the RAM limitations?

MWT. *RAM costs big time in processors, so there was only room for 29 byte-sized program steps. Twenty-nine steps was too long for most people to enter, but not enough moves to get a seven motor robot to do anything really interesting.*

To solve this, I came up with the reflex-call function so you could link-in any of the three six-step reflexes as single commands under the master program. This works either conditionally (robot waits for stimulus) or as a batch (robot just executes the routine and carries on).

Twenty-nine steps now become a very easy-to-work 84 steps that you can quickly program in pieces without a computer. You can set him up to do routines up to three hours long or longer, if he's in listen mode.

Q. I'd like to know if you used human motion or another gait model to design the four walking styles.

MWT. *None of the above. RS is not a devolved human; he's an evolved analog robot. Any similarities to humans or humanoid robots — either real or as might appear on the Discovery Channel — are coincidental. His walking was evolved from my non-linear, oscillator, biomorphic stuff.*

Q. Each hand LED looks like it was actually designed for IR vision to direct RoboSapien to react to objects or obstacles. Was that in the original design?

MWT. *Very well spotted. Yes, the original design used these to remotely detect objects, walls, doors, cliffs, and even other robots. Cost and complexity restrictions left this feature on the cutting room floor; however, you can play with the bot in the dark to see much of the original detection routines (Select-Pickup, for example).*

The reset position (Select-Stop) resets the hands to the ideal forward alignment for visual and touch sensor object detection. Occasionally, he'll get stuck, but not as often as he used to.

Q. Internally, the design looks like it's just inviting expansion. There is room for more than the four touch sensors in each foot, for example, with unused connections already present at connection points — BK, CN, etc. Are these ready for

As RoboSapien takes a step, the ingenious two bar linkage keeps the bottom of the foot parallel with the ground.

additional sensors or modifications?

MWT. *Because the feedback loop is edge sensitive, you can, in theory, add a wide range of 20 mS, parallel wired, pulse-generating sensors in the arms or feet. If you take apart his forearm, you will see that the grippers are rotatable, interchangeable, and socketed for your hacking convenience. The hands, legs, and arm shells have multiple places for the mounting of your own accessories. They're even labeled.*

For those with the hacking interest, I wanted to make the bot so it would be easy to get cool results quickly. You don't have to swap out his brain; it's conveniently optimized for your use. You can add laser pointers, motorized accessories, cameras, disco lights, sunglasses, furniture, etc. Use him as an actor in a fanfic ("These aren't the droids you're looking for. Oh, wait, yes they are.").

There are plenty of plays to purloin. When you do, post pointers.

Q. Can I replace the LEDs with, say, an 880 nm IR emitter at a 40 kHz modulation, pulsed at 20 mS and connect this through the existing touch sensor or does RoboSapien need a different nM/HZ range?

MWT. *920 nM at 635 HZ, 1 mW — otherwise it can interfere with the IR detector on his head. You can try building your own ranger, but many of the commercial units should do.*

Q. Does the 20 mS pulse need to be triggered high-low or low-high and sent with an acknowledge or with timing values? Am I getting way to complex, already?

MWT. *Hey, I love complex.*

The forearm sensor triggers respond to 20 mS edge transitions, either high-low or low-high. By generating filtered pulses of this length, your IR detector can share the same sensor feedback line as the touch triggers with little interference.

The robot is also designed so that a sugar cube camera placed on top of the head will be in the best place for optimal viewing.

Q. It looks like there are several unused connection points on the motherboard. Do these include ones for the camera?

MWT. *They are leftovers from his turbulent past. After RoboSapien killed a twitchy Aibo in an Istanbul bar fight, a Voodoo bot-doctor cursed him to lose his vision by pushing live laser pointers into a Pikachu plush. RS snorted and, after freeing the Ipod slavegirls from the Karaoke LINUX box, doffed his hat and swung into his WowWee JetCar courtesy of a sparking T1 LAN line.*

Alas, the curse worked; his sight dimmed, though the vision connections still remain. He feels it was worth it, though. Burp.

Q. How long did it take to create RoboSapien — from your first idea for it to the unit available now?

MWT. *I built my first in 1964: A wooden robot called "Mr Freckles." My mum still has it in England. I guess she should have taken me for treatment, but — in those days — psychiatry was still in its infancy.*

Like many, I've pondered humanform robotics for quite awhile; however, it took about three years to make this model.

Q. What did you start building bots with back then? How do you think technology has progressed to the state we have today, where RoboSapien can be sold for under $100.00?

MWT. *My first bots were wood, cardboard, and base electronics. Since then, I've built bots from many materials: teak, nickel, aerogel, Walkmans, platinum, and even gold.*

Technology didn't progress for this robot. There's

Designer Mark Tilden proves that dogs look like their owners — right down to the beady red eyes!

nothing in him that couldn't have been done 30 years ago. Principles that were developed years before most of us were even born (Turing, VonNeuman, Hasslacher, that crowd) just needed application.

Q. How much would this type of robot have cost a government agency 10 years ago?

MWT. *At a guess, to design it, approximately $10,000,000.00. To build it, maybe $50,000,000.00 per unit. It's a moot question, though, as no agency would want such a thing in reality — only in science fiction.*

Q. At first glance, it looks like the external wires, face shield, and other parts are decorative elements, but does every part serve a purpose?

MWT. *The cables down his arms carry signals and power and also keep him from getting stuck against walls. If you're using RS in the sun, flip the face shield down to help filter out solar IR. Nothing is decorative; everything he has is something he needs. He's all bot.*

Q. By the way, did you know the included RoboSapien cup makes a perfect place to put all the screws when taking it apart?

MWT. *A secret feature. :)*

Q. The control method is largely analog in RoboSapien; what are some of the flaws that you avoided by not using a strictly digital control system?

MWT. *I'm not anti-digital (I am, in fact, pretty familiar with it), but I do know what it's good for by hard experience. It can't do everything, no matter what the Turing Hypothesis says. If computers could easily handle the real world, we would have had effective personal robots in the 80s. All life is analog, but only one species out of 20,000,000 thinks that digital watches are a good idea (with respects to Douglas Adams). That should give you a hint.*

When it comes to robots, saying digital or analog is like saying food or water. Life is fine when fields combine, but don't let anyone tell you how you should build just because Bill Gates needs another billion. Look for other techniques. For example, it doesn't matter if you use chopsticks or a fork; all that matters is you use something to keep tidy.

There are minimal, elegant solutions out there. Some assembly is required.

Everyone thought that buying a red hat at the next Linux convention would be the wave of the future. Wrong.

Q. What do you think of the slightly more expensive Zero Force Point biped robots, like Sony's $40,000.00 Qrio, Honda's Asimo, or other models that use this technology?

MWT. *They're great, of course. Most use Zero Force Point (ZFP) to calculate the exact center of balance for the entire robot, then make sure that point is inside the stance frame. It's wonderful complexity, but I don't use that. It costs too much, takes too long, and can't handle dynamic loads; the units walk from the feet, not the hips and can't handle nonlevel surfaces, etc.*

The RS can walk over LEGOs without having to know where his feet are. Good alternative, I think.

Q. What's your favorite feature in the current version?

MWT. *His autonomous-wandering mode is fun and interesting. Setting his reflexes to bump his way around rooms, push boxes, pick up laundry, or walk into other bots and pick a fight, etc. The sort of thing that it took ages to do through PROM blasting autonomous robots can now be seen directly and changed quickly.*

Q. Can you tell me how a true analog system practically translates into a machine that serves as a functional example of Biomorphic life?

MWT. *The cool thing about advanced analog systems is that you can set them up to give you automatic design gain, where, for a linear increase in complexity, an exponential increase in functionality results.*

This only occurs, however, in loop regenerative systems capable of more autonomy than direction, so biomech naturally evolved around selfish, autonomous mode systems. Break that loop and your robot stands there patiently waiting for you to give it direction (RoboSapien). When it's closed, you get something more like my BIObugs, which moved by themselves for themselves.

The cool thing with biomech is that you can build

both the mechanics and control at the same time. Only if they work as sub-components will they work in the whole. This way, you can build a complex robot from scratch and see it work from the very first moment it's powered on. It works.

Q. What do you think about RoboSapien incorporating digital controls, in addition to the analog reflex design? Was there another way to include the remote control and programming abilities with purely analog control?

MWT. *Sure, but it wouldn't have been as convenient, expressive, or mass manufacturable. Digital control is great for complex, precision sequences and analog control is great for adaptive, real world power management. When they work well together, both can be minimal while keeping performance high.*

Q. Do you see the future of robotics as more of a blend of, say your Biomophic design, combined with voice recognition, digital reactions, and value judgment, like the brain sits in an environment of direct consciousness and leaves the details of hands, limbs, and organs to their respective levels of consciousness, but still under the mind's control?

MWT. *I like to think Biomorphic engineering provides a cradle into which AI could develop — not the only solution, just the one I use.*

Variations on the minimal system architectures of competent machines are my favorite topics. I've tried many — some with success — most with disastrous results. Being able to build quickly and effectively allows for measures of experience you can't normally ratify through simulation.

Get real. Unless you build it, how can you ever know? As for the future of robotics, I hope it'll be fun. I hope so. I have bots to build.

Q. Are there any other secrets you can share by the way of remote control functions, undocumented attack modes, or 802.11g wireless built-ins ... etc? :)

MWT. *Nope, but I can tell you he has 28 built-in "Easter eggs" and looks dead sexy in chrome.*

Another of these secrets Mark shared is a diagnostic mode included for anyone hacking away at the inner workings. Hold the right toe sensor while powering on, then release the right toe and press the left toe four times within five seconds. The robot will enter a diagnostic mode, so you can test each sensor individually. Try any of the Touch Sensors, give IR commands, or test the noise threshold of the Sonic Sensor. The diagnostic ends with a 1 kHz test tone. You can reset RoboSapien by pressing Select + Stop. This diagnostic mode also works to test any sensors you've added.

If you're wondering how to respond to feedback, just take a look into the robot's soul. Each eye is actually a group of six LEDs, each corresponding to a joint in motion or a sensor waiting for input. You can read all 64 feedback combinations yourself from points located on the main board, at P2.0 to P2.5, along with the other socketed connections.

I've found the mechanical design of RoboSapien to be as unique as the design choices themselves. As a robot that truly walks, has functional grippers, regenerative power, and is also easily reprogrammable, RoboSapien would already exceed the average owner's interests.

When you include the internal design — socketed, labeled, and ready to hack — you exceed expectations. RoboSapien is a compelling alternative for anyone extending the senses and abilities of any robotic platform.

You only need to peer into RoboSapien's soul and hack away ... **SV**

About the Author

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TETSUJIN TECH

INTRODUCTION TO PNEUMATICS IN ROBOTS

Part 2

by Alexander Rose

In this second part of the article on pneumatics, I will discuss all the components — from source to actuation. For most components, there are trade-offs you will want to weigh against the criteria of your task and design.

Please note that, in most sections, I will give you some of the industry terms for components, as they can be difficult to find without using the right terminology. For instance, you will find that the word cylinder is interchangeable with the words actuator, ram, pressure vessel, and bottle, depending on who you talk to.

With all of the components listed below, the very first thing you want to check is their rated pressure. Never use any component that does not have a rating and never use a component above that pressure rating. So, we will start with gas types and sources and then discuss regulators, buffer tanks, valves, lines and fittings, and, finally, actuators.

Gas Types and Sources

Most robots that use air from a compressor are ones that are built into their location or use a relatively small compressor onboard to charge the system. Onboard compressors use a fair amount of power, are often loud, and usually have difficulty keeping up with high volume requirements. They have the advantage, however, of being able to bring the system up to pressure without a person having to refill a tank. This means you only have to supply power to your robot instead of both power and tank refilling.

Compressor-based systems usually operate with a pressure switch to turn on the compressor when the pressure drops below a certain point and shut it off again when it reaches the maximum operating pressure. These systems have the added advantage of using the easiest to find commercially available components. Most industrial pneumatic systems in use today run off simple air compressors.

High pressure air or gas (HPA) systems refer to systems that store air or another gas — like nitrogen — at very high pressures (3,000-4,500 psi) and dispense the gas at operating pressure through a regulator. These systems require refilling when the main tank pressure drops below operating pressure. HPA systems can be made fairly compact, offer very consistent operating pressures, and can be built for short duration high volume tasks.

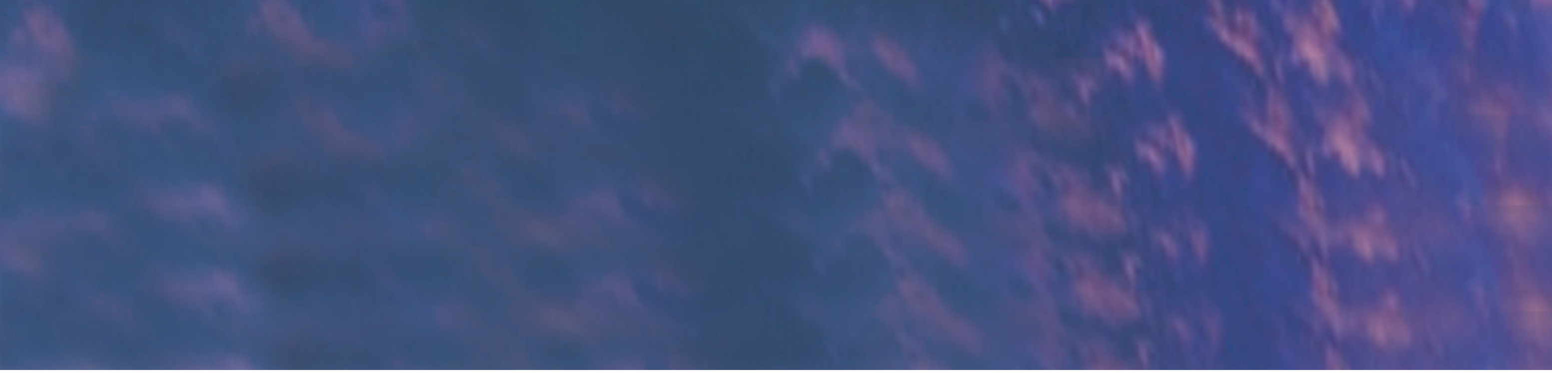
Most HPA systems utilize filament wound pressure vessels as the main storage tank; these can be very lightweight. (It should be pointed out that all HPA tanks are required to be DOT certified in the US and have regular tests done to ensure viability. They are all printed with the date of their last test and it is illegal to fill them if this date has expired.)

Other gases can be used in HPA systems beside air. Nitrogen is often used, as it's inexpensive and available in high pressure tanks from welding shops. The best source for small and lightweight HPA components is usually the paintball industry.

Liquefied gas systems (like CO^2) are some of the most difficult to use in pneumatics, but they offer some unique trade-offs. Gases that liquefy can store a tremendous amount of energy in a very small space. The gas is stored as a liquid and boils off at a pressure that depends on the ambient temperature.

However, this state change can wreak havoc in incorrectly designed systems. Gases moving from a liquid to gas state cause an endothermic reaction that makes everything they touch very cold. (This is why they are referred to as cryogenic gases in the pneumatics industry.) As they get cold, the pressure drops and the gas gets more dense or even turns into vapor or liquid.

If you are using valves, seals, and lubricants designed for room temperature gases, having



a cryogenic fluid in the system can cause damage to the components and create dangerous pressure situations. You will want to use low temperature, synthetic lubricants throughout the system to avoid stiction problems in the valve and actuator.

With liquefied gases, it's best to use aluminum tanks, as they are the best at conducting and dissipating the temperature shifts in these systems. (These tanks also require a DOT rating and recertification every few years.) Like HPA systems, liquefied gas systems are generally regulated down to operating pressure. Which gas you use, however, can change this.

One of the most widely used gases is CO^2, which changes state at around 850 psi at room temperature. However, it is possible to use a gas that liquefies at the working pressure of your system. Unfortunately, most of these low pressure liquefying gases — like propane and butane — are flammable, so caution must be used.

Liquid systems also have special filling requirements. The tanks being filled must be colder than the tank filling it and the filler tank needs to either have a dip tube or be upside down. Like HPA, the smallest and most lightweight CO^2 system components come from the paintball industry. Both CO^2 and HPA systems can be refilled by your local welding or paintball shop. Paintball shops can also sell you economical refilling systems.

Regulators

Regulators are used in most pneumatic systems. The regulator takes in pressure from a higher pressure source and lowers it to your operating pressure. The diversity of regulators on the market is huge. They are designed for specific gases, speeds, pressure differentials, and operating environments. Regulators are also usually the first point of restriction in a pneumatic system; you will want to choose one carefully.

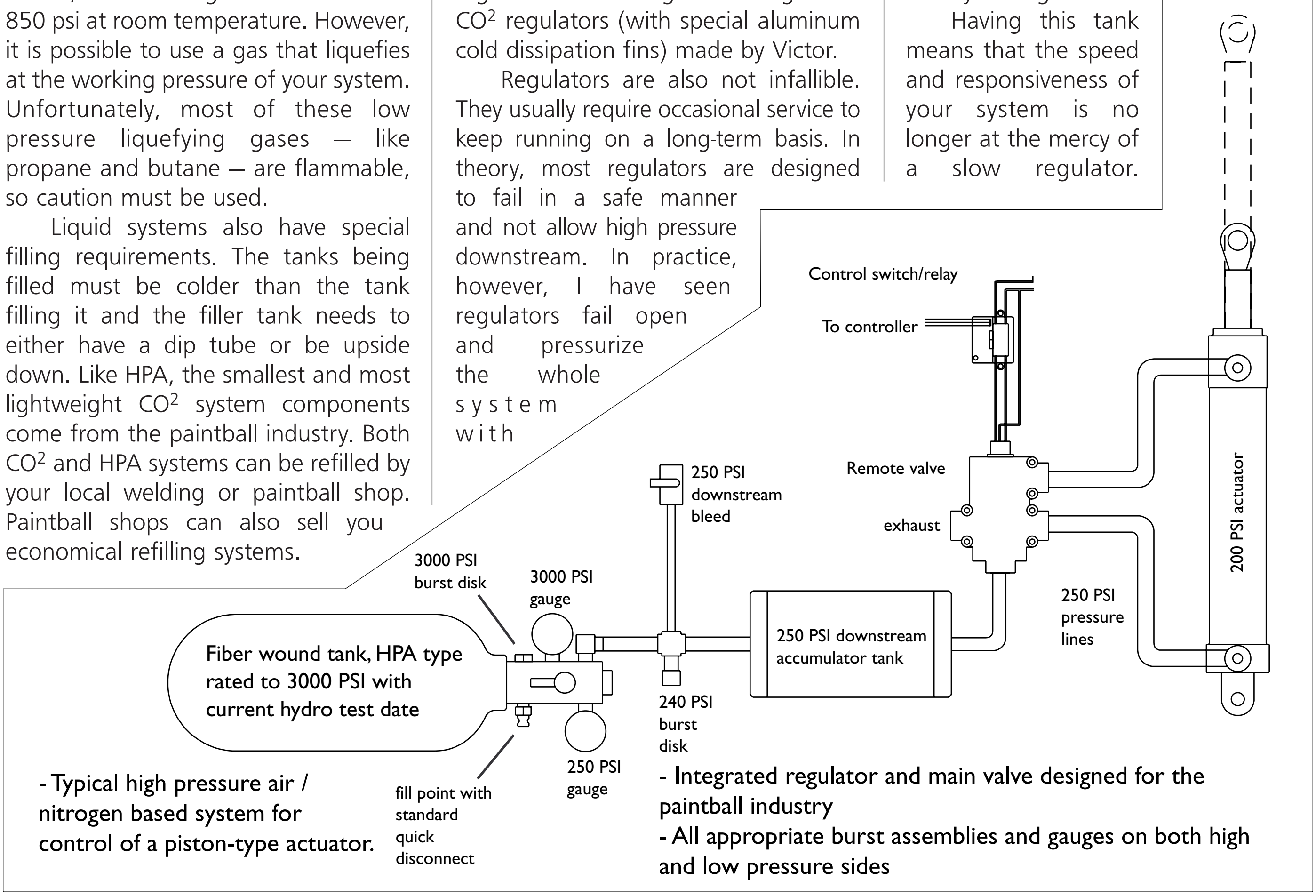
There are very small and light regulators developed for the paintball industry for both CO^2 and HPA, but, in general, these are not very high flow. There are some very high flow HPA regulators from Norgren and high flow CO^2 regulators (with special aluminum cold dissipation fins) made by Victor.

Regulators are also not infallible. They usually require occasional service to keep running on a long-term basis. In theory, most regulators are designed to fail in a safe manner and not allow high pressure downstream. In practice, however, I have seen regulators fail open and pressurize the whole system with dangerously high pressures. Some regulators have an overpressure relief valve for this, but, in some cases, you will have to install one yourself (more about that in the fittings section).

Buffer Tanks

Buffer or accumulator tanks are another crucial part to any good pneumatic system, especially high speed ones. Generally speaking, to get good responsiveness, you want a tank at the working pressure of your system, as close to the actuators or point of work as possible. In practice, this means having a buffer tank downstream from your regulator.

Having this tank means that the speed and responsiveness of your system is no longer at the mercy of a slow regulator.



- Typical high pressure air / nitrogen based system for control of a piston-type actuator.

- Integrated regulator and main valve designed for the paintball industry
- All appropriate burst assemblies and gauges on both high and low pressure sides

While it is possible to use very high throughput regulators and design them close to their point of use, this is usually cost- and space-prohibitive. Systems using a buffer tank will often have a source tank at a high pressure — around 850 psi for CO^2 or 3,000 psi for HPA — this tank will be regulated down to the working pressure of the system and that gas will fill the buffer tank to working pressure.

If the size of your buffer tank is large enough to supply the system for a full task cycle (like lifting an object and lowering it again), your system will be able to operate at maximum speed. To determine the size of your buffer tank, we have found the best rule of thumb is to calculate the volume of gas required by your actuators for a full cycle and add 50%. This 50% accounts for the pressure drop seen by the system when the gas starts leaving the accumulator and keeps the system moving fast.

Valves

Valves are generally one of the most challenging parts in any high performance pneumatic system. The first thing to verify about your valve is that its seals are compatible with your gas and any lubricants you may use. Valves have o-rings and other soft parts that can run into trouble when not used properly.

In general, air is neutral to most seal materials, but a liquefied gas like CO^2 can cause the valve to experience very low temperatures, causing the seals to become brittle. In addition, most pneumatic systems want to have some oil in them to keep these seals lubricated; this oil has to be compatible with your seal material, as well, or it will cause swelling or even disintegration of your valve seals.

For almost all gas applications, you will also want a valve known in the industry as normally closed and "bubble tight." This means that the valve's off state is closed and that no gas will leak by the seals. Some valves use metal-to-metal seals for extended wear or use with liquids, but they are constantly leaking when used with gases and are, therefore, not what you want.

The valve types used in most robotic applications are generally referred to as two-way, three-way, or five-way. This can be one of the more confusing parts of picking out a valve. A two-way valve has two ports: one in and one out. This is what you need to operate a pneumatic motor in one direction or to disburse gas (as in a fire extinguisher).

A three-way valve has three ports: in, out, and vent. Three-ways are required to power an actuator in one direction, with the vent allowing the ram to return to its starting position either by gravity or a spring return. Three-way valves — with a spring or gravity return — are usually the way to get the highest performance in an actuator system, as they don't have to vent high pressure from the other side of the actuator as part of their job.

Five-way valves are required to actuate a ram in two directions and have five ports for this task. These are usually larger, more complex valves, and are difficult to get in high pressures and throughputs.

Valves are generally rated in both psi (pressure) and cfm (speed). You will want a valve that can work at your operating pressure or higher and has the highest cfm rating possible. One note I have found about cfm ratings in the past is that there is no real standard for measuring this in the industry. Unlike testing pressure, it turns out that there are many "standard" ways to benchmark cfm. Not surprisingly, each valve company benchmarks their valves with methods that present their valves in the best possible light, so always take these ratings with a grain of salt.

Many valve manufacturers also give an orifice diameter spec with their valves. This refers to how large the internal opening is within the valve and speaks to the valve's throughput. The larger the orifice size, the faster the throughput. Ideally, you will match the orifice size to the internal diameter of the lines coming in and out of the valve.

While cfm measures how fast gas moves through the valve, it is not the only performance spec on the valve that will concern you. Some large, actuated ball valves, for instance, have huge throughput times, but very slow actuating times. For fast actuating times, there are a few options: Direct acting solenoid valves are often considered the fastest valves and pilot operated poppet or rocker valves are usually the next best (and are often required for high pressure and throughput, as solenoids lack the power).

In choosing a valve, you will find experimentation to be your best ally, as the variables are many. As far as layout goes, you will want your valve as close to the point of work as possible. Long lines between it and the buffer tank or actuators will mean slower response and actuation times.

Lines and Fittings

Lines and fittings are an often overlooked aspect of any pneumatic system. Correct choices here can make the difference in testing, assembly, and final performance. If your system requires fittings on the high pressure side (between the gas source and

FORMULAE FOR PNEUMATIC DESIGNS

Actuator Force = Area x Pressure
Area = (1/2 Bore) ^ 2 x π

Push Stroke
V = [(1/2 bore) ^ 2 x π] x throw
V = [(1/2 4) ^ 2 x π] x 6
V = (2 ^ 2 x π) x 6
V =(4 x π) x 6
V = 12.56 x 6
V = 75.36 cubic inches

Pull Stroke
Vrod = [(.5) ^ 2 x π] x 6
Vrod = 4.71 cubic inches
75.36 - 4.71 = 70.65 cubic inches

General gas law: P1 / P2 = T1 / T2.

regulator), make sure these are rated for the higher pressures.

We generally like to use the Teflon lines covered in stainless braid, as they are very durable, conduct the cold well for CO^2 systems, and are rated upwards of 3,000 psi. For these lines, we try and use the flare or JIC connection standard, as it requires no sealing tape (like Teflon) and allows for connection at any angle. If this is not available or possible in your application, standard pipe thread with Teflon tape is the usual standby.

All components downstream of your regulator can be rated for the working pressure of the system, but using higher ratings here doesn't hurt and gives an extra margin of safety. For most purposes, I highly recommend using "push to connect" fittings — also referred to as "fast connect" fittings. These are low pressure fittings and lines (up to 300 psi) that allow you to rapidly reconfigure systems by cutting lines with scissors and pushing them into the fittings to connect them.

You can use different line materials that have different minimum bend radii and come in multiple colors and pressure ratings. As far as line size and diameter goes, there are a few considerations. Basically, you don't want the gas to have to expand and compress multiple times as it goes through your system. You should size all lines to the smallest restriction in the system, often the valve orifice.

One other key fitting you will want — especially in liquefied gas systems — is a pop-off valve. These come in preset or adjustable versions and they basically bleed off any excess pressure in the system above that setting. These can save your components (and anyone standing near them) in the event of a regulator failure or if some liquid CO^2 gets past the regulator and expands into the gas state on the other side. If you find your system going too fast, there are throttle valves that can be put on the incoming and exhaust sides of your actuators to tune the speed.

It is always worth your time to add gauges, on/off valves, and quick disconnects to any system. You should have appropriately scaled gauges on the high and low pressure sides of the system to allow easy visual confirmation if the system is pressurized. On/off valves to turn off flow out of the source tank and another to bleed the pressure downstream will allow you to keep the pressure in the tank and depressurize the system to make it safer to work on.

If you are going to fill the tank while it is in the robot, you will want a quick disconnect fitting to allow easy filling. You should never have to unthread taped pipe fittings for filling. For all these fittings, the paintball industry has made several very small and light versions for both high and low pressure requirements.

Actuators

Actuators — also called rams or cylinders in the industry — are the last part of your system; they are also the part that does the actual work. There are also rotary actuators, rodless actuators, and pneumatic motors. For the purposes of this article, I will discuss one and two directional rams only, but most of the principles are the same.

Rams that are only powered in one direction are called single acting. These usually have no port to pressurize the return and may have a built-in spring return. Actuators with two ports for powering the stroke and return are called double acting. You can use a double acting ram in a single acting application, but not visa versa.

Your choice of actuator starts with the amount of work you need to do. Basically, by multiplying the ram's piston surface area (π x D) by the pressure in psi gives you the force in pounds your actuator will exert. Note that this says nothing about speed — that is a function of the cfm of your total system and the valve response time.

You can also trade speed for power in the geometry of your mechanical design. If you are also calculating the force of the return stroke, remember that you must subtract the area taken up by the ram's piston rod, as the gas on that side of the actuator has a reduced surface area to push against, thus return strokes are less powerful than push strokes.

Some rams allow disassembly — permitting them to be serviced — where others are press fit or crimped together — making them light and small, but disposable. Lastly, if you are trying to build a very fast actuating system, make sure there is a damper or external travel stop in the system. Most actuators will self destruct when operated extremely fast if this precaution is not taken.

With all these components, you should be able to build a pneumatic system to do almost any applicable task. It is possible to build more advanced systems with travel sensors, pulsing or variable valves, and regulators, but I would recommend starting with the gear in this article first, as you will learn a great deal by building even the most simple of systems. Remember when laying out your final system that the path of the gas should be as short and simple as possible for high performance and responsiveness. Always wear the proper safety equipment and test with low pressures first. Good luck. SV

ABOUT THE AUTHOR

Alexander's informal training began when he moved to a junkyard at the age of seven. His formal background is in industrial design, for which he received his honors degree from Carnegie-Mellon University in 1995. He began working with pneumatics in the paintball industry in 1987. Since then, he has used pneumatics successfully in championship fighting robots, an air powered circular saw converted into a dragster, 300-foot-tall flame throwers, and, most recently, one pound micro fighting robots.

Hack This Budget AIRPLANE

by L. Paul Verhage

While shopping at my local Wal-Mart, I came across the Estes Sky Rangers Pee Wee Flyer — a single channel, mini R/C (remote controlled) airplane designed for backyard use. What attracted my attention to this R/C airplane is that it was on sale for less than $20.00. The box artwork shows a small airplane and R/C transmitter with a single button. When I noticed the single button, I asked myself, "How on earth do you fly an airplane with a single button?" Then I wised up and asked if I could hack this thing for more appropriate uses.

I paid my $20.00, took the airplane home, and started some investigating. The result of this find is an inexpensive radio that I use in robotics. I imagine that the modification described here is pretty standard for any R/C toy, so the procedure can be used for other inexpensive R/C units that you come across.

However, be aware of the frequency you are using and do not interfere with other users of the band. From my research, any R/C frequency is legal to use with cars, boats, and airplanes, except the 75 MHz, which is not legal for use with R/C aircraft.

Looking Into the Guts of the Pee Wee Flyer

The transmitter and receiver of this airplane operate in the 27 MHz band. The specific frequency of my airplane was set by a quartz crystal tuned for 27.145 MHz (the frequency is stamped on the side of the crystal housing). This frequency is one of six in the 27 MHz band used globally for cars, boats, and aircraft [1].

Since both of the airplanes that I hacked used this frequency, I imagine that they all operate at 27 MHz.

The airplane's receiver and motor are powered from a small set of three N-cell sized, rechargeable cells. When discharged, I measured a voltage of 3.3 volts across the battery; when charged, I measured 4.5 volts across the battery. The airplane contains a rapid charger for its internal battery. The rapid charger uses six C size cells to hit the airplane's rechargeable battery with 9 volts.

The servo for the airplane rudder is a tiny plastic box containing a wire coil on an axle and a neodymium magnet glued to the outside of the box. When the R/C receiver energizes the coil inside the servo, the servo axle rotates to the opposite extreme. The servo has no intermediate positions; it's either all the way clockwise or all the way counter-clockwise. The servo does not have much torque compared to the standard R/C airplane servo.

The R/C controller is a blue plastic box that operates with a standard 9 volt transistor battery. It has a 12 inch whip antenna made from piano wire. The end of the wire antenna is wrapped into a loop to protect your eyes. Pressing the R/C controller button turns on the transmitter. It appears that there are pulse width modulated signals being transmitted; either the radio is fully on or fully off.

The airplane's rudder is rotated to one side. As a result, it constantly turns to one side as it flies. Pressing the single R/C button causes the airplane's rudder to snap to the opposite side. The longer you press the button, the longer the airplane turns to the opposite side. With infrequent button pushes, the airplane flies in a gentle turn. Increasing the frequency of button pushes causes the airplane to fly in a straight line or even turn the opposite direction.

Using the Estes Sky Raiders for robotics involves removing the transmitter and receiver, making modifications to the boards, making two simple interfacing boards, and then writing code. The first step in a project like this is to violate the warranty of the product — one of my favorite activities.

Removing the Transmitter

First, remove the transmitter from its case. On the back of the transmitter case is a large label and beneath it is the single screw that keeps the plastic case together. After you remove the screw, pop open the plastic case. When you open it, the whip antenna will immediately fall to the ground. Don't panic; the antenna was only pressed against the transmitter's PCB and no

For Inexpensive Robot Communication

mechanical connection was broken.

Pick up the antenna and set it aside for now; we'll fix its mounting problem later. Note that there's a plastic catch molded into the transmitter box that holds the PCB. Pry the catch back and the transmitter PCB will pull lose — except for where it is connected to the battery box. Cut these two wires (red and black).

Removing the Receiver

You must seriously damage the airplane's fuselage to remove its receiver, so don't hack this R/C controller if you plan to fly the airplane. Otherwise, peel off the artwork stickers on the outside of the airplane to expose the fuselage's seams. Carefully split the fuselage and peel away the styrofoam using your fingers.

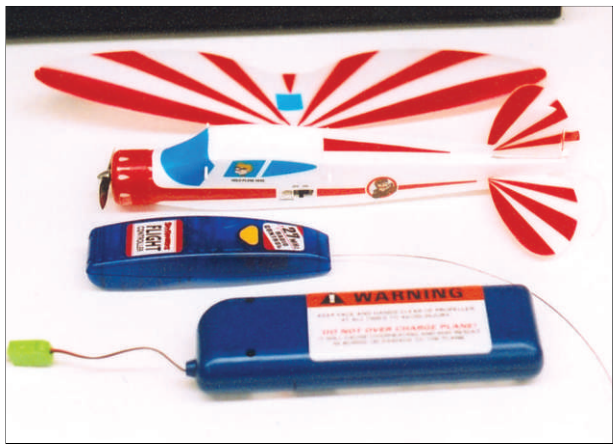
The receiver's antenna is a small gage wire taped to the fuselage. If you cut open the fuselage, you take a risk of cutting the antenna. Antennas are cut to a length specific for their frequency, so it's critical that you do not damage it. Once you have split open the fuselage, carefully pull the antenna wire out of the fuselage.

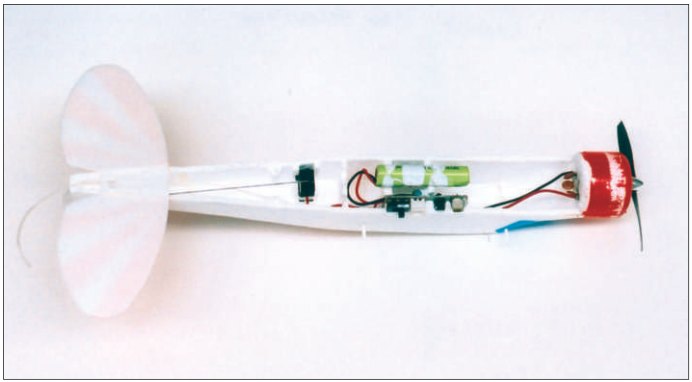
Cut the servo wires close to the servo and away from the PCB. As I don't see a need for this servo, I recommend that you just leave it in the fuselage. Like the servo, the motor is not needed, so clip the motor wires somewhere near the motor.

Finally, cut the battery wires near the battery, as you won't be using the airplane's battery.

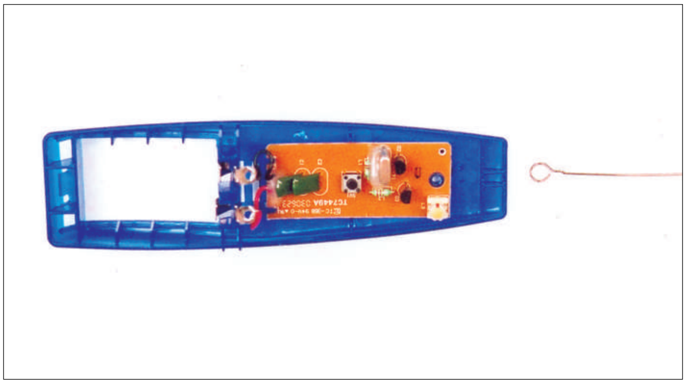
At this point, you have two PCBs. The transmitter PCB is missing its antenna and has two wires — red and black — dangling from the bottom. The receiver has a total of seven wires hanging from it, along with one antenna, two battery wires, two motor wires,

The patient prior to its receiver-ectomy.





After the fuselage is gone, the internals are easy to remove.



There isn't much to the transmitter.

and two servo wires.

Hacking the Transmitter

The first task is to attach the antenna permanently to the transmitter PCB. Since the antenna is made from piano wire, it will not solder to the PCB. After reading *Nuts & Volts*, I knew just how to attach this antenna. Cut a short length of #24 AWG stranded wire and strip it of insulation. Wrap the wire loop at the bottom of the antenna in copper wire. Wrap the wire reasonably tight and keep it looking neat. Now, tin the wire-wrapped loop in solder.

Where the antenna fell loose, you'll notice the transmitter PCB has a ring-shaped copper pad (the pad is about 1/4 inch in diameter). This is where the antenna was pressed against the PCB. Add a little more solder to the pad before proceeding. Now, press the wrapped and soldered antenna against the pad and heat them with a soldering iron. The solder will melt and unite the antenna to the transmitter PCB.

The transmitter's momentary — normally off — push button switch is mounted to the center of the transmitter PCB. I left the switch in place on the transmitter PCB so I could use it as a test button.

For the microcontroller, install two wires to the push button switch. Drill two holes into the PCB to act as a strain relief for the wires. Before I drilled my strain relief holes, I lifted the PCB to the light and noted that it is not a multi-layer board. I could clearly see the location of copper on the PCB and avoided drilling through it.

Use a small finger drill to make two small holes in the PCB about 1/4 inch from the right side of the switch. Locate one hole at the top of the switch and the other at the bottom of the switch. Cut two lengths of #24 AWG stranded wire to a length of about 12 inches. Strip about 1/2 inch of insulation from one end of each wire and tin the bare ends.

Pass the wires through the drilled holes from the push button side of the PCB and fit them beside the soldered pads of the push button switch. Solder one wire to the top two pads of the switch and the other wire to the bottom two pads of the switch. Hold the wires in place as you heat the pads and wires.

The wires to the battery terminals are red and black. Remove the dab of glue holding them to the top of the PCB and note that the top silk of the PCB labels the pads on the PCB as red and black. Heat the underside of the PCB and remove the two wires. Solder the leads of a battery snap to the two pads, making sure you solder the right color wire to the right pad. If you want to locate the battery snap farther away from the transmitter PCB, then solder two lengths of wire to the PCB pads and then solder the battery snap to the wire extensions.

Be sure to cover the soldered connection between the wires with heat shrink tubing. You may want to cut the positive lead in the power cable and solder in a power switch. A small, sub-miniature toggle switch will be ideal. If you don't add the power switch, then be sure to disconnect the 9 volt battery

TRANSMITTER CODE

```
'{$STAMP BS2}
asciiCharacter    VAR     Byte
serialData        VAR     Bit(8)
counter           VAR     Nib
transmitterPin    CON     9

Send_Data:
  PAUSE 5000
  DEBUG "sending", CR
  asciiCharacter = "a"
  serialData(0)=asciiCharacter.BIT0
  serialData(1)=asciiCharacter.BIT1
  serialData(2)=asciiCharacter.BIT2
  serialData(3)=asciiCharacter.BIT3
  serialData(4)=asciiCharacter.BIT4
  serialData(5)=asciiCharacter.BIT5
  serialData(6)=asciiCharacter.BIT6
  serialData(7)=asciiCharacter.BIT7

Start_Bit:
  HIGH transmitterPin
  PAUSE 1000

Send_Byte:
  FOR counter = 0 TO 7
    IF serial(counter) = 1 THEN Send_Low

Send_High:
    HIGH transmitterPin
    GOTO Send_Next_Bit

Send_Low:
    LOW transmitterPin

Send_Next_Bit:
    PAUSE 1000
  NEXT
  LOW 9
  GOTO Send_Data
```

from the transmitter when you are finished using it for the day.

The Transmitter Interface Board

Now that the transmitter has been modified, you need to add the microcontroller interface. Instead of operating the transmitter by tapping the bare ends of the switch wires together, we'll let a transistor make the connection for us.

A transistor with less than 0.7 volts between its base and emitter has near infinite resistance between its collector and emitter, so, when one switch wire is soldered the collector and the other switch wire is soldered to the emitter, the transmitter will not transmit. Once 0.7 volts is applied to the base of the transistor, though, the apparent resistance between the collector and emitter decreases.

With enough voltage on the base, the resistance between the collector and emitter approaches 0 Ω. To the transmitter, this looks like a switch closure. To protect the transistor and microcontroller from excessive current, a current limiting resistor is added to the base of the transistor. To make the process of activating the switch apparent to humans, an LED is added. The entire transmitter interface is soldered to a small piece of perf board. You need the following parts to assemble the interface board:

- 2N3904 NPN transistor
- 560 Ω resistor
- LED
- #24 AWG stranded wire (use two colors)
- Perf board (RadioShack P/N 276-170 works well)

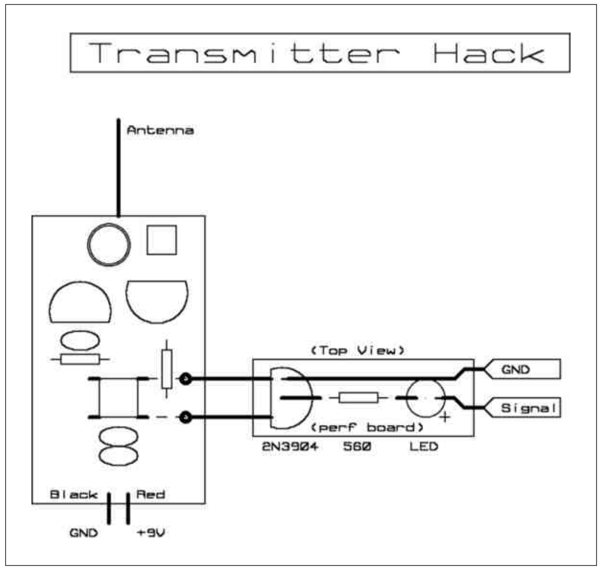
The receiver diagram illustrates the parts placement on the perf board. The view is of the top of the board, therefore soldering is on the underside. Pay close attention to where the switch wires connect to the transistor. The top wire from the switch goes to the emitter and the bottom switch wire goes to the collector. I had trouble making the circuit function properly when the wires were switched.

I used a green LED for my interface board. A green LED has a voltage drop of about 2 volts. If you use TTL (5 volt) logic to operate the transmitter (which is typical for microcontrollers like the BASIC Stamp), then only 3 volts is available to operate the transistor. I have found that a 560 Ω resistor was sufficient to both set the brightness of the LED and to saturate the 2N3904 transistor. A red LED only drops the voltage by about 1.7 volts, if you are concerned about pushing out enough current for the interface board. I don't think this should be a concern, except with low voltage microcontrollers.

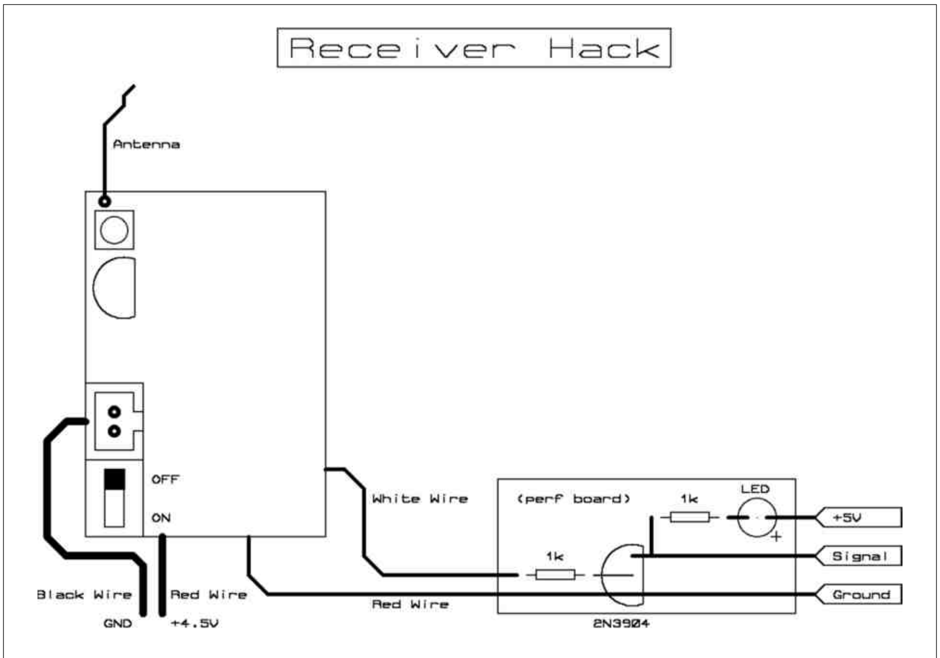
After soldering up the interface board, you'll need to terminate the control cable (marked as Signal and Ground in the diagram) as is appropriate for your microcontroller project. I used a male header that plugs into the receptacles on my robot.

To protect against accidental shorts, complete the transmitter and interface board as follows. Cut a 3-inch long piece of clear, 1/2" diameter heat shrink tubing (depending on the size of your LED, you may be able to use 3/8" diameter heat shrink). Slide it over the interface board and shrink it. This keeps most of the stuff off of the interface board while allowing you to see the LED.

Instead of covering the transmitter board in heat shrink, I zip tied it to a small piece of correplast (corrugated plastic). I sandwiched a 1/8" thick



Interfacing to the transmitter PCB.



Interfacing to the receiver PCB.

sheet of foamed neoprene between the transmitter board and correplast to fill the gap between the boards. I picked up the neoprene foam at a craft shop; it's sold under the name Foamies.

The only thing that remains to be done is to write the code that operates the transmitter. The code is available for download from the *SERVO* website (**www.servomagazine.com**).

Receiver Code

```
'{$STAMP BS2}
counter         VAR     Nib
firstRead       VAR     Bit
serialData      VAR     Bit(8)
asciiCharacter  VAR     Byte

Check_For_Start_Bit:
  IF IN5 = 1 THEN Check_For_Start_Bit:
  PAUSE 1250

  FOR counter = 0 TO 7
Get_Data:
    firstBit = IN5
    PAUSE 1
    IF IN5 = firstBit THEN Store_Bit
    GOTO Get_Data

Store_Bit:
    serialData(counter) = temp
    PAUSE 1000
  NEXT

Read_Character:
  asciiCharacter = 0
  FOR counter = 7 TO 0
  asciiCharacter = asciiCharacter * 2
  asciiCharacter = asciiCharacter +
  serialData(counter)
  NEXT
  DEBUG ASC? asciiCharacter

GOTO Check_For_Start_Bit
```

Hacking the Receiver

First, cut the wires used to power the motor as close to the receiver board as you can. You don't need these wires and leaving them dangling around is just looking for trouble. There are only two sets of wires remaining on the receiver PCB (ignore the wire antenna). The first set is the heavier gage red and black wires that are used for power. The remaining set is the thinner gage red and white wires that control the servo.

It's more convenient to work with the receiver if you extend the remaining wires. I found #24 AWG stranded wire to be adequate for this purpose. Be sure to cover the soldered connections with heat shrink tubing.

After extending the wires (if you desire to do so), add the battery case. The original batteries created about 3.6 volts nominally, however, I have operated the receiver with 4.5 volts successfully.

So, it appears that you can use alkaline or NiCad cells to power the receiver.

Slide a short length of heat shrink tubing over the thicker gage wires, then solder the wires from a three "AAA" cell holder to the thicker gage wires. Be sure you do not solder the battery holder backwards.

Afterward, cover the soldered connection with the heat shrink tubing. There is no need to insert a power switch because the receiver has its own switch.

The Receiver Interface Board

Next, you need to assemble the receiver's interface board. To protect the microcontroller, you'll use a transistor as a receiver-operated switch. A pullup resistor insures that a solid logic high or logic low is applied to the microcontroller. My design also includes an LED for visual confirmation of a signal. You'll need the following parts to make the receiver interface board.

- Two 1K resistors
- 2N3904 NPN transistor
- LED
- #24 AWG stranded wire (use three colors)
- Perf board

This time, three connections to the microcontroller are needed: ground, signal, and power. The receiver diagram illustrates the parts placement on the perf board. As with the transmitter, this diagram is from the top of the perf board and the solder connections are made on the underside. You'll need to terminate the cable from the interface board appropriately for your microcontroller project. Just like I did with the transmitter, I used a male header so I could plug it into the I/O port of my microcontroller board.

When the receiver receives a signal from the transmitter, it tries to operate its servo. This voltage is used to saturate the base of the transistor (the first 1K resistor limits the current the receiver can send to the transistor while still allowing the receiver's 4.5 volt signal to saturate the transistor).

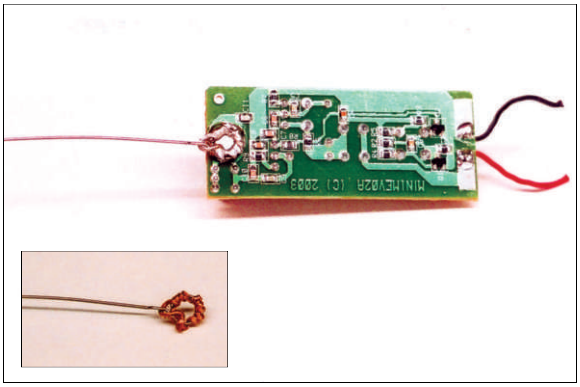
The resistance between the signal and ground wire goes to zero, making the transistor act like a closed switch. Now the microcontroller sees its signal wire shorted to ground (at a logic low). When the transistor saturates, the +5 volt signal is also shorted to ground, letting the LED turn on.

When there is no voltage from the receiver, there is no short to ground, so the microcontroller's signal sees 5 volts (a logic high) from the pullup resistor.

We'll wrap up the receiver hack by protecting it from accidental shorts circuits. Slide a three-inch length of clear heat shrink over the interface board. I ended up using a wider diameter of heat shrink than I used on the transmitter interface board.

Because the underside of the receiver board is not as flat as the transmitter board, use hot glue to mount the receiver board to a small piece of correplast.

However, still use a zip tie to attach the cable from the receiver to the correplast. This forms a strain relief and prevents accidental tugs from pulling wires off of the receiver board.



Reattaching the Tx antenna to the PCB.

The hacked Rx with its three "AAA" pack.

Software

The software I used to test my R/C is available on the *SERVO* website listed previously. I wanted to send a single ASCII character as serial data. I found that the R/C has a significant lag in its response, so I sent the character at a baud rate of one. This is not a high speed radio link, but it appears that it can operate faster than one baud.

For my needs, though, I only need to send a few bits of data. I was able to see this transmitter and receiver communicate between two modules of an aerobot successfully at one baud. **SV**

NOTES

1. I found the frequencies for R/C vehicles at **www.easy-RC.com** and at **www.rcxotic.com** The frequencies permitted for 27 MHz are: 26.995, 27.045, 27.095, 27.145, 27.195, and 27.255.

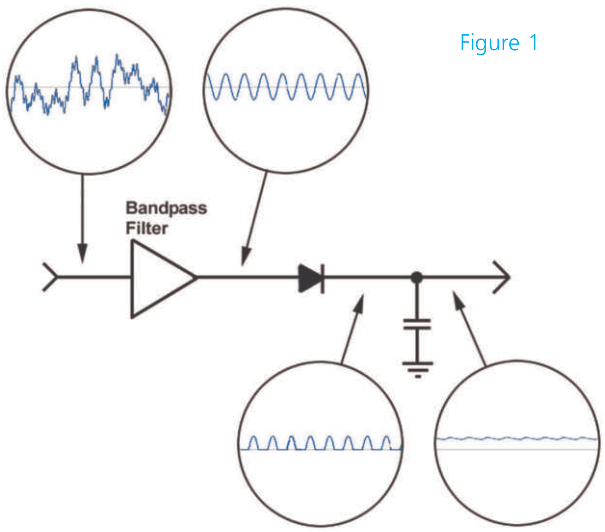
Transforming the World — One Frequency at a Time

by Jack Buffington

This month's column deals with the Fourier transform (pronounced "four – ee – aye"). The Fourier transform allows you to extract information about periodic waveforms. More specifically, it allows you to break down complex periodic waves into a series of sine and cosine waves that add together to create the complex wave.

The Fourier transform isn't very useful on its own. It is more of a tool that allows you to break complex data down into something that is easier to understand. You can build a circuit that performs a similar function to the Fourier transform for a single frequency. This circuit passes the input signal through a high Q band pass filter, takes the output from the filter, rectifies it, and then smoothes the signal with a capacitor. This would leave you with a voltage that is proportional to the amplitude of the frequency that the filter lets through.

Figure 1



Equivalent analog circuit for a single frequency

To help you understand what they can be used for, here are a few examples of things that can be done with Fourier transforms:

- The mesmerizing bar graphs that you see on things like stereo graphic equalizers or in audio programs — such as WinAmp — are generated by doing Fourier transforms. Usually, these display lower frequencies on the left side and higher frequencies on the right of the bar graphs.

- Fourier transforms are commonly used in voice recognition software. The waveforms of speech can be pretty complex, but the amplitudes of different frequencies — as produced by the Fourier transform — can make identifying the different sounds of speech easier.

- Recently, astronomers have been reporting that they have been finding planets in solar systems other than ours. They currently can't actually see these planets through a telescope. What they are doing instead is taking advantage of a phenomenon called "red shift." The apparent color of a star changes slightly, depending on whether it is moving toward or away from us.

  This is essentially the light-based version of the Doppler shift that you hear as a car passes you. If it is coming toward you, its pitch is higher than if it is going away from you. Planets don't just orbit a sun that sits fixed in space. The gravity between a sun and its planets moves the sun, as well. This causes changes in the star's red shift. By recording the red shift of a star over a period of several months or years, the scientists can use Fourier transforms to detect the presence of planets.

- Fourier transforms can be used in any situation where there is a periodic waveform that you need to detect or extract information from. The above cases are just a few examples, but they show how varied the applications for Fourier transforms can be.

How to Do a Fourier Transform

This section will show you how Fourier transforms are actually done. Fourier transforms rely on some higher math. Hopefully, this article will make the math relatively painless to follow. We will need to cover a few preliminary topics before we do actual Fourier transforms. The first of these is how to multiply waveforms together.

Multiplying waveforms together is essentially just a matter of taking the heights of each waveform at the same point along the horizontal axis and multiplying those heights together. This gives you the height at the same point on the horizontal axis for the answer. Here are a few rules of thumb to think about when you are multiplying waveforms:

- In any place where either of the two waveforms being multiplied crosses zero, the result is also zero. This is the case at the blue line.

- If a point on the horizontal axis has a positive height on both waveforms or a negative height on both waveforms, then the point in the resulting waveform will be positive.

- If a point along the horizontal axis has a positive height on one waveform and a negative height on the other waveform, then the point on the resulting waveform will be negative.

These rules of thumb get us part of the way there, but there is still more to do. Let's look at Figure 2, where we are multiplying the top two waveforms together to arrive at the bottom waveform.

We'll call the top graph sin(x) and the middle graph sin(2x). Our units for the horizontal axis are radians so that the red line represents $\pi/2$. The units on the vertical axis simply depict magnitude. In a real world situation, they might be units of brightness, voltage, pressure, dog barks per hour, or anything, really. At $\pi/2$, sine has a height along the vertical axis of .707. For the middle waveform, we have $\sin(2 * \pi/2)$, which becomes $\sin(\pi)$. This equals 1. To get the resulting point on the bottom waveform, we have .707 * 1 = .707. If you did this for every point of the top two waveforms, you would eventually end up with the bottom waveform.

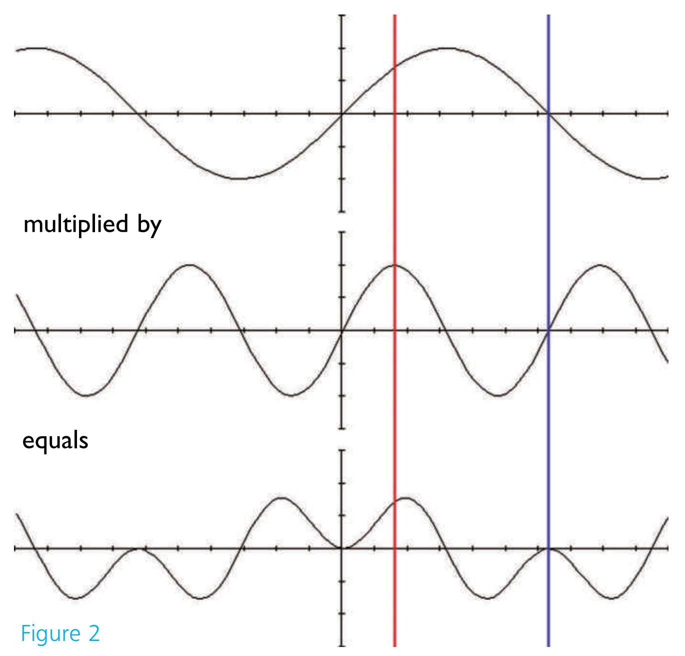


Figure 2

Finding the area of a waveform is the other key skill needed for doing Fourier transforms. In Figure 3, we have the waveform sin(x). The areas that are above the origin are positive and are filled with green. The areas below the origin are negative and are filled with yellow. The end result is that sin(x) has an area of zero because the negative area is equal in magnitude to the positive area, thereby cancelling each other out.

This is good to know, but how can you mathematically find the area of sin(x)? It seems like this would be a pretty tricky task, but it really isn't if we sacrifice a little precision. Take a look at Figure 4. In each, we are splitting the X axis into discrete amounts and creating rectangles the width of each segment that are as tall as the measure where the waveform passes through the leftmost edge of the segment.

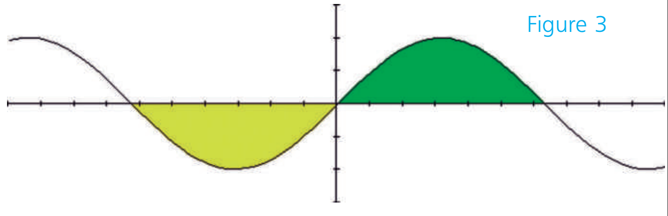


Figure 3

It is easy to find the area of a rectangle. The formula for finding the area of a rectangle is length multiplied by height. To find the area for the waveform, simply add up the areas of all of the rectangles for one full wavelength. Remember that rectangles that are below the origin have negative area. The first diagram splits the waveform into just four segments per wavelength. This doesn't give us a very accurate idea of

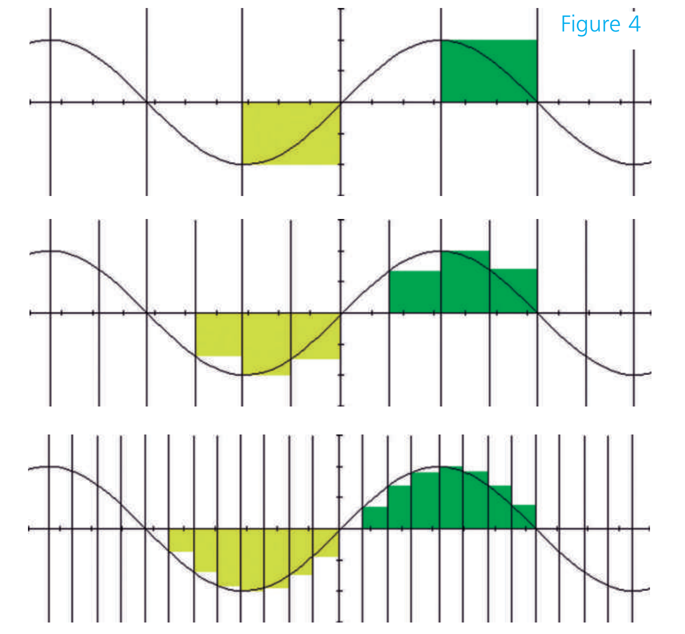


Figure 4

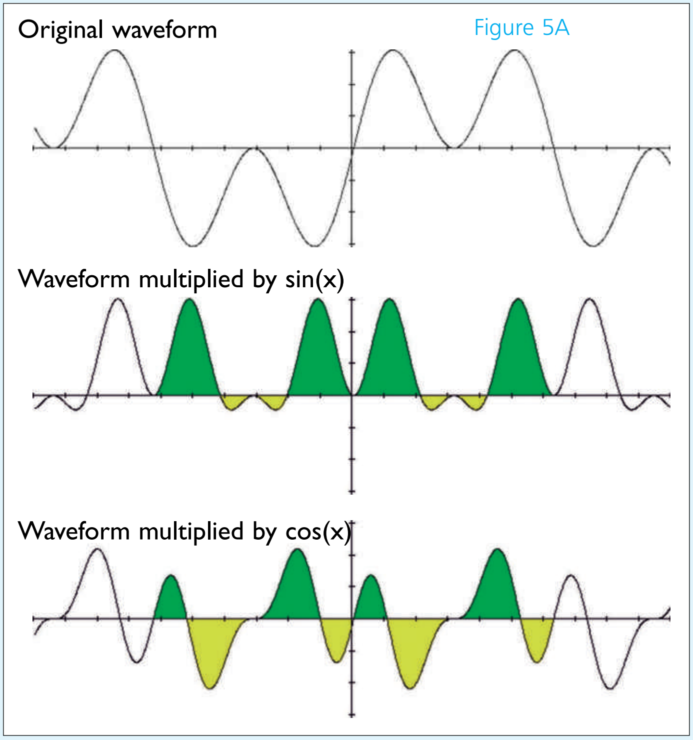


Figure 5A

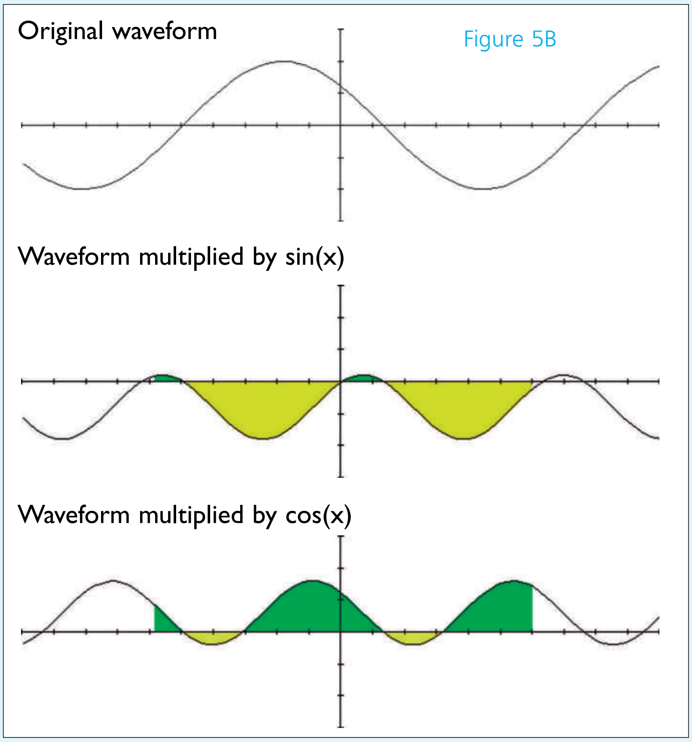


Figure 5B

the area of the waveform. As you move down through the graphs, the waveform is split into progressively more segments. This allows you to find an increasingly more accurate area for the waveform.

Now you know how to multiply different waveforms together and find their area! Let's tie these two methods together and look at how we can apply these skills to do Fourier transforms.

The essence of doing a Fourier transform is to multiply the given waveform by sine and cosine waves that have the wavelength that you are trying to detect and then find the areas of the resulting waves. Knowing that, let's take a look at the graph of sin(x) + sin(3x). Since we know the formula for this waveform, we know that it contains the wave sin(3x).

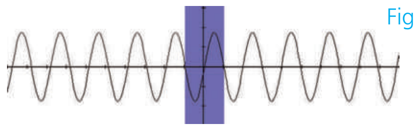


Figure 6A

Looking at one wavelength is not very accurate

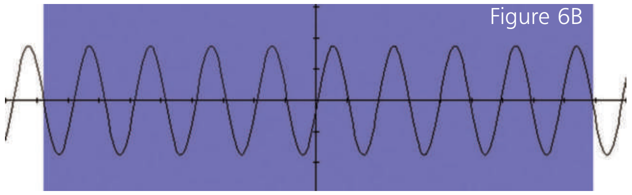


Figure 6B

Looking at several wavelengths increases accuracy

Here is an example of how we would detect the sin(3x) waveform in it by using a Fourier transform.

If we multiply the original waveform by cos(3x), we end up with an area of zero. When multiplying by sin(3x), we get a positive area. If the area of either waveform is non-zero, it indicates that it is possible that this wavelength was present in the original waveform.

Let's look at a waveform that is not so nicely aligned with either the cosine or sine wave (Figures 5A and B).

When we find the area of this waveform multiplied by sin(x), we get a negative area and, when we multiply by cos(x), we get a positive area. These are both non-zero numbers, indicating that this wavelength was very likely present in the original waveform.

If you are looking to find the amplitude of that wavelength, then you will need to take one additional step. We'll need to refer to our old friend — the Pythagorean Theorem — to find the amplitude.

Pythagorean Theorem:
$$A^2 + B^2 = C^2$$

To find the amplitude of that wavelength, simply add the squares of the areas of the two waveforms that were created by multiplying the original waveform by sin(x) and cos(x). Take the square root of that sum and divide by pi.

In the example above, the waveform multiplied by sin(x) has an area of -2.62. The waveform multiplied by cos(x) has an area of 1.73. The squares of these are $6.864\overline{4}$ and $2.992\overline{9}$, respectively. Add these together to get 9.8573. The

square root of that number is 3.1396. That number divided by pi gets us very close (.999) to the correct answer of 1. The slight amount of inaccuracy is due to the method we used to measure the area of the wave.

A Slight Correction

Earlier — for the sake of simplicity — this article stated that, if you detected a non-zero area in one of your multiplied waveforms, it would indicate that the wavelength that you were multiplying by would likely be present in the original waveform. Like the electronic equivalent described at the beginning of the article, the Fourier transform will detect signals that are close to the intended wavelength. You can vary the range of frequencies that the Fourier transform will detect by changing how many repetitions of the desired waveform you look at.

In all of the examples shown in this article, a slice of time that was exactly one wavelength long was used for the calculations. This will successfully detect that frequency, but will also detect other frequencies with similar wavelengths, as well. If we only use the period of time that our desired wavelength occupies to do our calculations and there is a component wavelength in the original waveform that is close to the wavelength that we are trying to detect, it will match the different wavelength fairly strongly.

To increase the selectivity of the Fourier transform, we will simply need to look at a larger slice of time. Wavelengths of a similar length to the one that we were looking for would have less influence on the result (Figures 6A and B).

Fourier transforms can be a hard thing to wrap your mind around. Hopefully, if this article hasn't given you a clear understanding of how to do Fourier transforms, it will have at least introduced you to what the Fourier transform can do for you. What was described here was a basic building block.

Most applications that do Fourier transforms actually do something called the Fast Fourier Transform. This allows your program to look at a whole range of frequencies at the same time. Each frequency still requires all of the same calculations, but the execution is speeded up drastically by intelligently remembering the results of previous calculations.

Next month, this column will lighten things up a little by covering a slightly easier topic. That's not to say it's any less important — my goal is to keep giving you the tools you need in order to become an excellent roboticist! SV

Author Bio

When not writing for *SERVO Magazine*, Jack runs Buffington Effects, a company that designs and builds animatronics and motion control devices for the entertainment industry. Check out his website at **www.BuffingtonFX.com**

LOW CO$T COMBAT BOT DRIVE

by Steven Schmitt

One of the challenges of building a combat bot is designing the drive train. It seems that motors are either too slow, too weak, too heavy, or just too expensive.

However, the automotive industry uses a large number of small, electric motors and they are both cheap and readily available.

There are two main classes of automotive motors: geared motors and direct drive motors. Geared motors include windshield wiper motors, power window motors, and power seat motors. Any of these would be too slow for use as the main drive motors in bots. Direct drive motors that are useable would be heater fan motors and engine cooling fan motors. Starter motors have plenty of power, but overheat very quickly.

Figure 1 shows several direct drive automotive motors. At the top left is a common engine cooling fan motor that was used on many 1990s cars, including the Metro, Aspire, and most Toyotas. The top middle motor is also an engine cooling fan motor and was used on many Toyotas. I believe it has about the same HP as the EV Warrior motor that many people in combat robotics use. The motor on the right is another engine fan motor that was used on many 1990s Fords. It looks like an EV Warrior on steroids. The motor on the bottom is a heater fan motor that was used on late 1980s cars, such as the Probe and Toyotas. This is a very small sample of the available motors that have robotics uses.

Direct drive engine cooling fan motors have an advantage, as they are more compact and able to fit in the engine compartment and are also lighter weight. However, they typically have a very short output shaft, making it harder to attach a sprocket. Note that the top left motor in Figure 1 has a sprocket attached to it. The top left and bottom motors in the figure have nearly identically sized armatures and equal power, but the heater fan motor (bottom) is longer, weighs 5 ounces more, and has a long output shaft.

While two auto motors may look alike, the windings might be different.

For example, the Ford engine cooling motor shown in Figure 1 would have different winding when used in an Escort or in a Lincoln Mark VIII. The Escort would have a high speed, low torque motor, while the Lincoln would use a low speed motor with a large fan for less noise. Also, different auto manufacturers may use the same motor for 10 or more years with only small differences in the mounting holes and electrical connections.

Most automotive motors are timed to run in just one direction, but the difference is small enough that it can be considered inconsequential. Much attention is given to match a CW motor with a CCW motor when using EV Warrior motors. I have found that my bots run straight even with mismatched motors.

While all automobile motors are rated at 12 volts, it is a meaningless rating. The motor RPM is determined by the

FIGURE 1

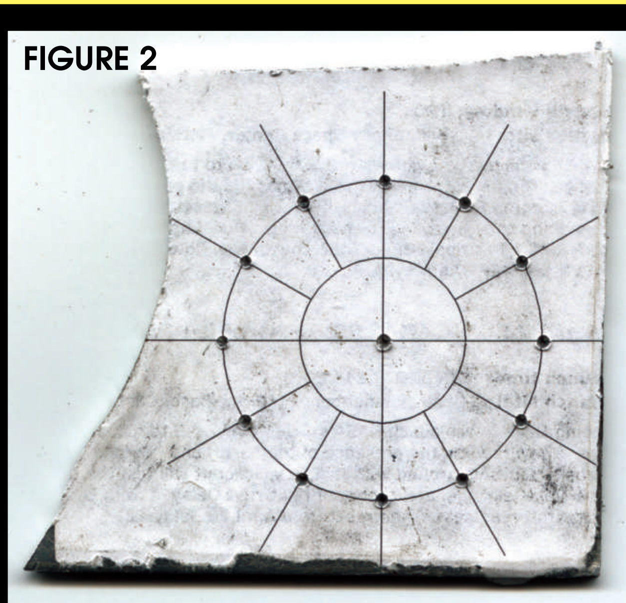
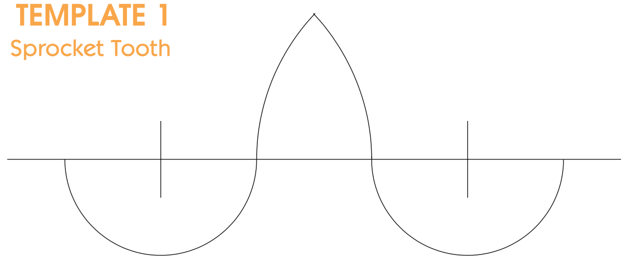


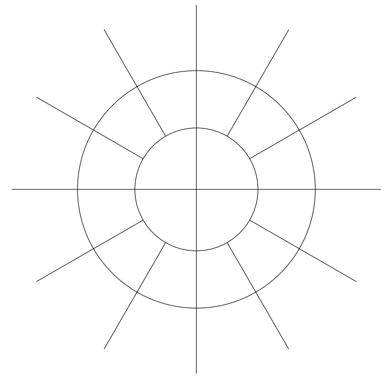
FIGURE 2

applied voltage and the torque and heating are determined by the current. In some cases, it may be better to increase the voltage well above 12 volts and gear the motor deeper to reduce the torque load, thereby cutting the current and heating.

TEMPLATE 1
Sprocket Tooth



TEMPLATE 2 Drilling Template



These motors are easy to rewind. For example, a motor with 11 turns of 19 gage wire could be rewound with 18 turns of 21 gage wire. Both windings have a cross section of about .01 square inch of copper to make them equivalent. The 18 turn motor would use a higher voltage and less current to generate the same HP and heating. The only reason to rewind a motor would be to match the motor to the batteries and speed controllers.

Of all the other types of motors used in automobiles, only power window motors are of much interest. Power window motors generally have a brake so that the window does not creep down. This is desirable for a winch-type application where the brake can hold any load the motor can lift.

Type	Pitch	Width	Roller	Strength	Notes
.1475	.1475"	.090"	.072"	180 lbs	
#25	.25"	1/8"	.13"	875 lbs	
#35	.375"	3/16"	.20"	2,000 lbs	
#41	.5"	1/4"	.306"	2,400 lbs	
#40	.5"	5/16"	5/16"		
#410	.5"	1/8"	.306"		Wide bicycle chain
	.5"	3/32"	.306"		Narrow bicycle chain
#420	.5"	1/4"			Motorcycle chain
#428	.5"	5/16"			Motorcycle chain

TABLE 1. Roller Chains

Starter motors have awesome torque, but overheat very quickly.

Also, most starter motors are series wound, which makes them hard to reverse. On the other hand, a series wound motor has a very fast top speed and, with enough battery power, can out-torque anything. The torque of a series wound motor is proportional to the square of the current, while the torque of a permanent magnet (PM) motor is only proportional to the current. We used series wound starter motors on our middle weight bot and the results were quite good.

The easiest way to transmit power from the motors to the wheels is with roller chains. The types of roller chains that can be used are listed in Table 1. Most builders use 35 chain for small bots because it is strong, light weight, and has fairly small sprockets. Type 25 chain can be used for the first stage of a two-stage reduction where the breaking load is less. Type 40 and larger would be used on large bots. Types 420 and 428 are motorcycle chains that can be purchased for reasonable prices from J. C. Whitney Company; however, these chains are too heavy for small bots.

Bicycle chain comes in two sizes: 1/8" wide for single speed bikes and 3/32" for derailleur bicycles. Both have a 1/2" pitch, which is the same as types 40, 41, 420, and 428 chain. Bicycle chain has a breaking strength of about the same as type 35 chain. However, it is narrow and has a tendency to jump off the sprockets, especially in the case of derailleur chain that is designed to jump sprockets.

With aggressive chain guides, either type of bicycle chain can be made to work as well as other chains. The main disadvantage of bicycle chain is that the sprockets are 1.33 times larger than type 35 sprockets and twice as large as type 25 sprockets. It requires a fairly large hull to contain the larger bicycle chain sprockets.

As bad as bicycle chain is, there are some major advantages in using it. Bicycle chain is usually free and it is possible to make the sprockets using basic tools.

A single tooth on a roller chain sprocket is formed by four arcs, as shown in Template 1. The bottom of the tooth is an arc that fits the roller and the sides of the tooth are arced so the roller can roll off the sprocket. To make a sprocket, the bottom arcs are formed by drilling a circle of holes. The sides can be formed on a simple jig mounted on a 4.5" grinder.

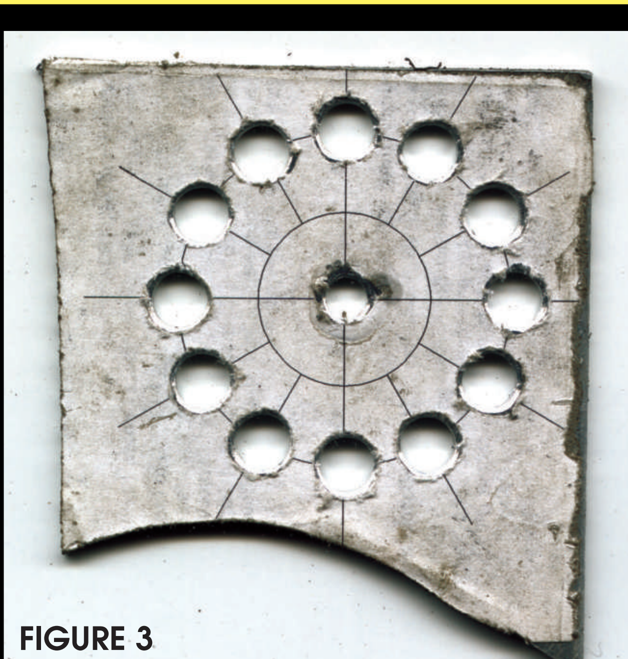


FIGURE 3

FIGURE 4

The first step in making a sprocket is to create a drilling template, as shown in Template 2. Draw a circle with the radius given by the following equation: R=P/[2*sin(180/T)], where P equals the chain pitch and T equals the number of teeth on the sprocket. The pitch for bicycle chain is .5" so a 12 tooth sprocket would start with a circle with a .653" radius.

Next, divide 360 degrees by the number of teeth to get the number of degrees between adjacent teeth. For a 12 tooth sprocket, 360 divided by 12 equals 30 degrees — the spacing between the teeth. Draw the radial lines at 0, 30, 60, 90, 120, and 150 degrees to get a drilling template like the one shown in Template 2. I used Corel Draw to create my templates, but any drawing program could be used. Note that the center has been whited out so that only the 0 and 90 degree radials show to make it easier to see the center cross hairs.

I have used both steel and aluminum for sprockets with both types of bicycle chain. They all seem to work equally well. For the 1/8" wide chain, I used a large aluminum road sign. For the 3/32" chain, I used a smaller road sign that was thinner. My local scrap metal dealer sells old road signs, but a quick online directory search will locate a scrap metal dealer in your area.

The drilling template is attached to a metal blank with

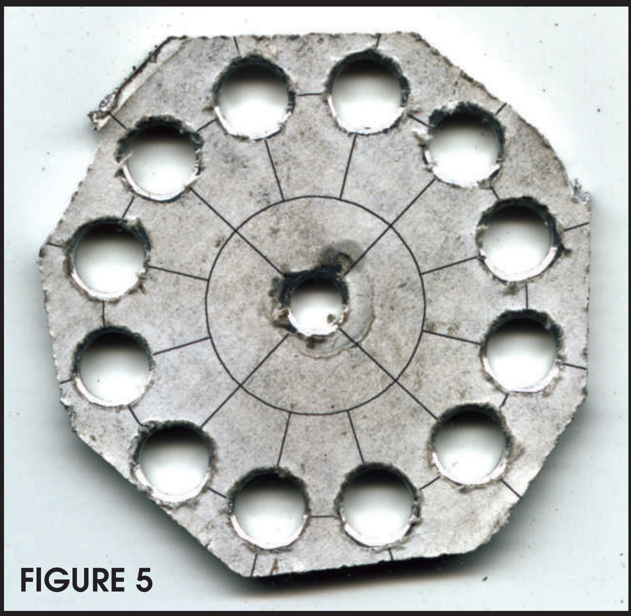


FIGURE 5

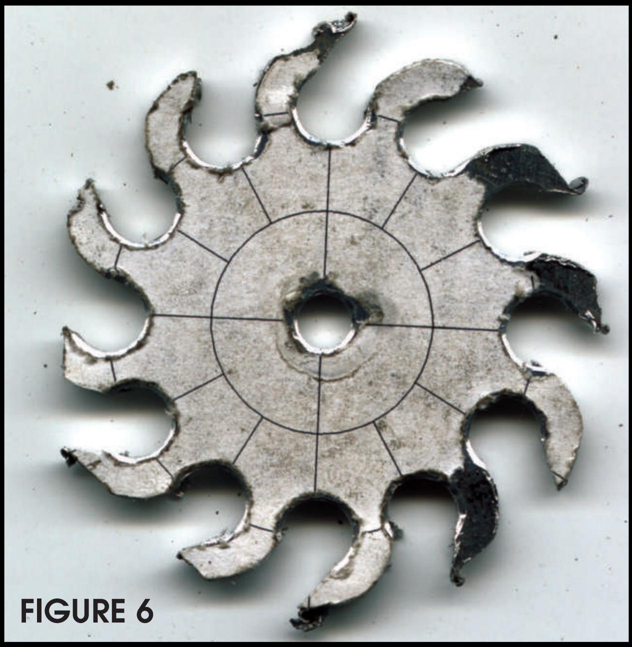


FIGURE 6


FIGURE 7

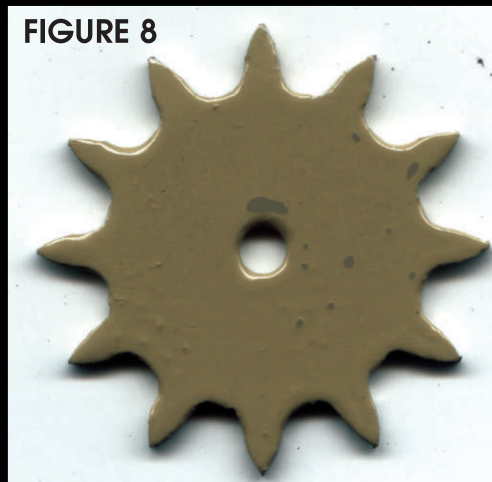


FIGURE 8

rubber cement and the positions of the holes are center punched, as shown in Figure 2.

Next, use a drill press to drill the 12 holes that form the bottom of the teeth and a small pilot hole at the center, as shown in Figure 3.

The grinding jig that I use is shown in Figure 4. Using a spare grinder shield, I made a small work table. A 5/16" pin was placed near the edge of the grinding wheel so the sprocket blank could be “spun” into the grinder, thus forming the sides of the tooth. The 5/16" pin should be adjusted so it is 11/32" from the grinding wheel.

At this point, a warning is in order. While grinding the sprocket, the grinder will be pointed straight at your face and you must use a full face shield to protect your eyes from metal bits.

Figure 5 shows the drilled blank after it has been rough cut to a size that fits the grinding jig. Figure 6 shows the blank after one side of each tooth has been ground on the jig and Figure 7 shows how the blank was placed on the grinding jig. Each hole in the blank is placed over the 5/16" pin and the blank is spun clockwise into the grinding wheel to form the curved sides of each tooth.

The blank is turned over and the process is repeated to form the other side of each tooth. After being de-burred, the final sprocket will look like the one in Figure 8. If the sprocket is iron, it can be welded to a hub. For aluminum sprockets, we use screws and epoxy adhesive to attach the sprocket to a metal hub or to a wooden wheel.

Figure 9 shows our middle weight bot after a tangle with the 80 pound arena spinner at TCMech Wars V. Note the Honda starter motor in the lower center with the drive sprocket and chains driving the large wooden wheel on the left side. The soot-covered device at the top left of the photograph is a flame thrower. The right side has been mostly destroyed by the arena spinner. This simple, low cost bot has a 5-7 record at TCMech Wars and has participated in 15 or more shows at the 2001 and 2002 Minnesota State Fairs.

Figure 10 shows the same middle weight bot carrying a refrigerator for the 2002 Minnesota State Fair. With the refrigerator, the total weight was over 300 pounds and the bot was a show hit. Seeing a Fridge Bot lurching around the arena, dumping trash out of a swinging door, and mock fighting a heavy weight bot is entertaining.

Next year, we plan to have a Stove Bot ready for the State Fair. It will have multiple flame throwers shooting fire out of the oven and burning food on top. SV

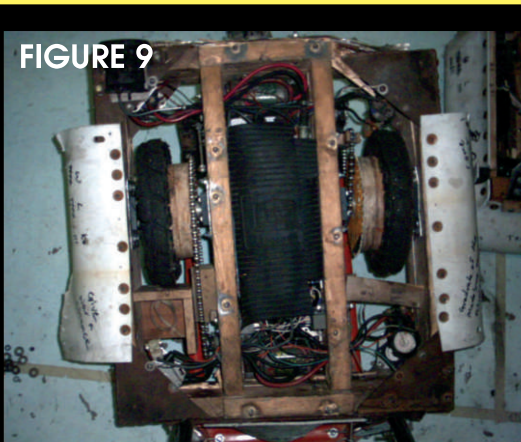


FIGURE 9

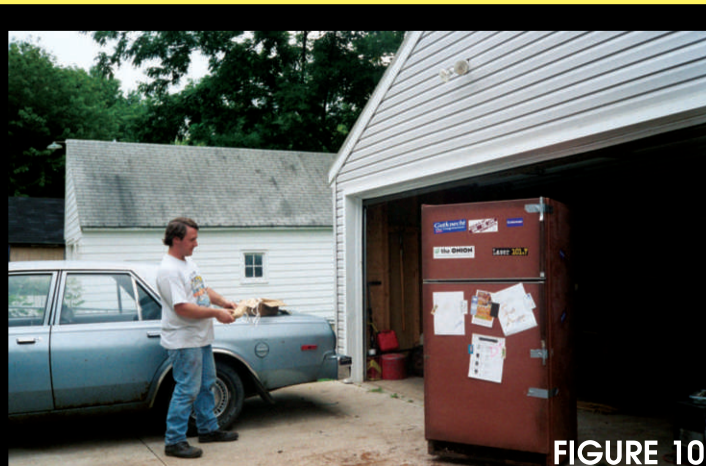
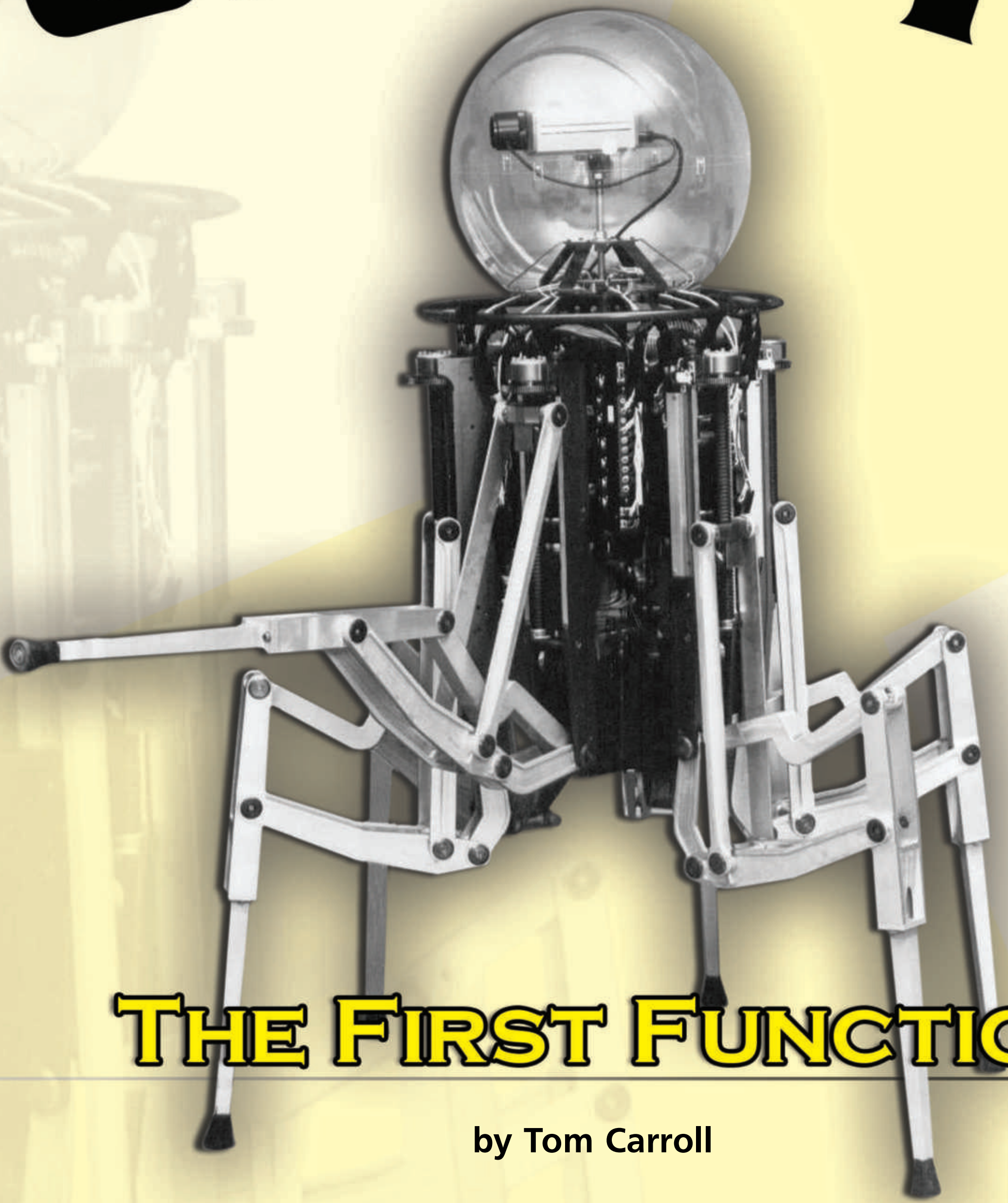


FIGURE 10

ODEX 1



The First Functionoid

by Tom Carroll

Several *SERVO* readers have asked about the Odex 1 robot. In talking with *SERVO* editor Dan Danknick, we felt that an article about the development of the Odex was timely and would prove to be quite interesting. With the okay to write the article, I felt that there would be ample information available on the Internet through Google. Wow, was I surprised. There are many references, but only one good article from *Robotics Age* magazine, circa 1983.

My next step was to go to Odetics, which is now called Iteris Holdings. In changing names and changing to a vastly different product line from that of the early 80s, I learned that most of the early technical data had been thrown away just weeks before — including photos and documentation on Odex. Thanks to some great people from Iteris, I was able to find the information for this article.

Back in the early 80s, I first became acquainted with this very unique Odetics robot. With my ocean engineering education and antenna testing background, my work involved almost everything but robotics. It was my interest in hobby and experimental robotics that caught the interest of our Rockwell division's chief engineer. He had seen a few articles written by me about the field and wanted to know what the state-of-the-art in robotics was at the time and how we could use this new technology in our space businesses. He figured that, if one of his engineers liked to "play" with robots, maybe he could also help the company get into this

papers on my space robotics projects and to gather information about other developments by other companies and universities. The most enjoyable trips were to all the university and government labs that I visited on the side, but I met the most diverse and interesting groups of people at these conferences.

I remember well the moment when I first saw the Odex robot in the spring of 1983. I saw the conference session title on the program and decided that it sounded interesting. The picture showed Odex standing tall, like a metal, six-legged octopus (or would that make it a sextapus?). I worked my way into the room along with about a hundred other people — most of whom had manufacturing backgrounds.

After a short introduction by an Odetics spokesperson, the room darkened and the presentation began. This is quite often a

new technical field in a more serious way.

Even though I knew nothing about industrial robotics, I was tasked with exploring implementations of robotics for use in our manufacturing processes, as well as space applications for our customer, NASA. These were the days when many companies wanted to be part of the new "robotics revolution." I quickly discovered that writing and delivering a paper at a conference not only granted me free entrance to the conferences, but also coaxed Rockwell into sending me there. As a result, I was sent on yearly trips to the annual RI/SME (Robotics International of the Society of Manufacturing Engineers) conferences that alternated between Detroit, MI and Chicago, IL each year to deliver

signal for some people to begin to nod off after getting a good meal below the hatches, but not this time. I still remember the images of this human-sized, giant spider walking off the back of a small pick-up truck. A few minutes later — with the help of an L-shaped bracket attached to the truck's bed — it actually lifted the back end of the 2,100 pound truck off the floor by pressing its head against the outstretched arm of the bracket (Figure 1).

Holy Cow! No one nodded off during this session. Other views showed the robot striding across the floor at a man's pace. The Odex could change the arrangement of its six legs and easily pass through a door. It could climb into and out of a truck bed and walk up inclined ramps. There was no tether; it was all self-contained. Most of the attendees were familiar with one ton industrial robots that could maneuver a 40 pound welding head around a car's frame, but not a 370 pound robot that can easily lift four times its weight.

Figure 2 shows one of Odex's developers, Robert Drap, holding one of Odex's arms.

A Little Background

Robot experimenters have long been fascinated with walking machines. Many of the robot kits available today are based on hexapod — six legged — platforms. These six legs are usually arranged on two sides of a rectangular base, not equally spaced about a circular base. This seems to be an odd means of movement to us; when we think of ways to get from one point to another, we naturally think of the way that we humans and animals traverse the surface of the earth. The early robots of science fiction movies were always walkers, even though the "walking" was accomplished by a person in a "robot suit."

Several major corporations developed walking robots, such as the huge, four-legged, gasoline engine-powered "robot walking truck" built by General Electric. Sony's AIBO series and the i-Cybie are very popular four-legged robot

dogs. Yes, there are some very unique bipedal robots made by Honda, Sony, and other Japanese manufacturers, but very few large walking robots have ever made such a technological "splash" as Odetics' Odex.

Odetics, formed in 1969, became well-known and respected for quality audio, digital, and video recording equipment. They were particularly proud of the fact that they had captured over 70% of the world's market for space-borne magnetic digital tape recorders. This market dried up after the advent of solid state, Flash, and other memory devices, but Odetics turned to other ventures, such as large, automatic tape retrieval libraries. These machines reminded me of a huge X-Y chart recorder where a robotic "hand" could be programmed to rapidly go to a specific compartment and retrieve a video tape cassette and then go to a commercial VCR and place the tape in the VCR for playback. This and many other Odetics products are an offshoot of the Odex development.

Odetics intended this robot to be part of a new era in the growing robotics industry in the early 1980s. Not a bit similar to Unimation's early "tank turret" manipulators that were used in many automotive and other types of factories, the Odex was intended to serve another purpose. Odetics management saw the unit as a robot that could perform the typical tasks ascribed to industry, yet walk away from the job site and do tasks in another area of the factory. Later versions of the Odex were configured to perform tasks in areas that were hazardous to humans or inaccessible to conventional tracked or wheeled vehicles. The debut of such a unique robot caught industry analysts by surprise, as no one in the robotics field had ever heard of Odetics.

Odex 1 began as a vision of robot experimenter Steve Bartholet, who happened to work for Odetics as a mechanical engineer. With a degree in mechanical engineering from Washington State University, it was a natural tendency for Steve to become interested in robotics as a hobby. He had seen many of the "typical" wheeled robots that had been built by others, but he longed for a robot that could traverse uneven ground and carry a very large load. The robot had to have the ability to change its profile (to be able to climb stairs or go through narrow openings), in addition to agility in its movements, strength, stability, and a self-contained power source. Walking robots seemed to be the answer. He worked through several leg configurations before deciding upon the final design used in the Odex 1. Figure 3 shows the plywood mock-up of the "articulators" — or legs — on the Odex.

Steve's robot design ideas reached Odetics management, particularly Joel Slutzky, the company president. The two talked about the possibility of Odetics actually constructing Steve's design. Unlike most companies that take an existing or potential customer's request and present a proposal, Odetics decided to "go it alone." Odex 1 was designed and built without specific applications or customer requirements — a major gamble for a small company. Slutzky wanted to protect the company's competitiveness and long-term growth.

Steve sat down to determine just what attributes he wanted to incorporate into his unique robot. It was a major departure from any existing industrial machine in existence at that time — or even today. Instead of being mounted in a fixed position in an automated assembly line or even being a mobile AGV (Automated Guided Vehicle) that was programmed to follow a specific path to deliver parts or mail, this robot had to be flexible in many environments. Odetics gave it the moniker of "Functionoid" due to its many functions. The Odex also had to have unprecedented strength-to-weight capability, as well as extreme agility. These were tall orders.

Let's get into the design of Odex. Figure 4 shows the configuration of each of the six "articulators." These are the keys to the overall design of the Odex. It is a great mechanical design of basic simplicity. The Z-shaped horizontal arm piece swivels from a fixed point below the structure and is fastened to the top of the leg. The second L-shaped piece is fastened to the same point and is connected to the extension actuator to cause the leg to move outward and inward. The third leg element is the horizontal piece that takes most of the force and is connected to the leg a bit below the top.

The largest of the three motors on each leg is the vertical motor. It is connected to a leadscrew/nut assembly to create the lifting force. A quick look at the drawing shows the end of the vertical actuator arm fastened about one-fifth of the way out from the pivot point. To create a force of 300 pounds at the end of the swivel arm holding the leg, the actuator must exert 5 x 300 — or 1,500 pounds — of force and that is with the end of the leg directly below the end of the swivel arm. That is a great deal of force for a small linear actuator, even with what appears to be a 3:7 gear ratio. A much higher ratio would not have allowed the quick movements required of the articulators.

The second of the leg actuator motors is the extension motor that is a self-contained gearmotor/lead screw

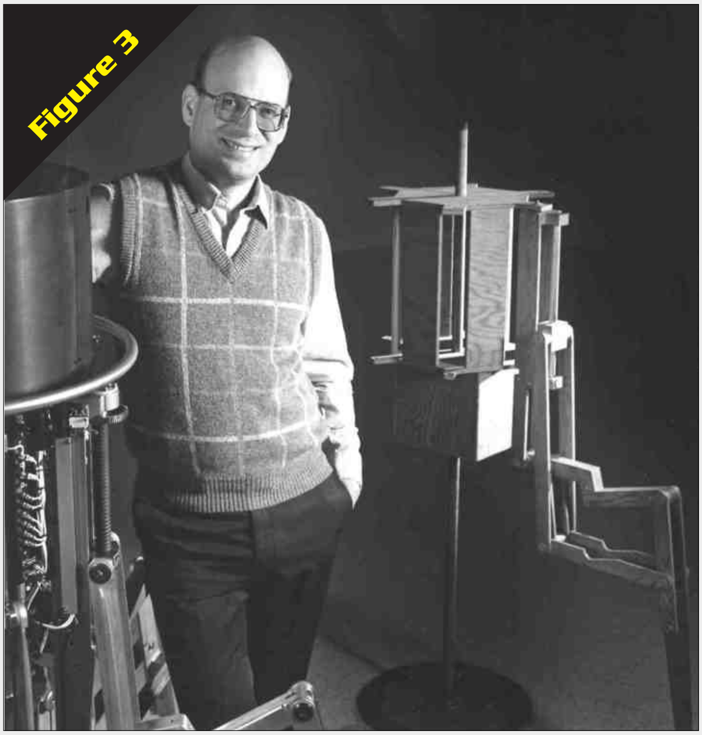


Figure 3

assembly. This motor does not need to be as large as the vertical motor, as it only needs to move the leg in and out. Of course, the approximately 2:1 ratio in the L-bracket requires twice as much force from the actuator, but the horizontal movement is also twice as much. When the actuator is at full extension, the longest part of the L-arm is forced horizontal and allows the V actuator to draw the leg upward to a compact stowage configuration. That is the reason for the Z in the horizontal piece — to allow the top of the leg to be pulled close to the robot's body.

The third of the Odex's actuator motors is the swing actuator. Since the Odex has a circular arrangement for its six legs, each of the legs cannot swing fore and aft at the same rate or amount as is done by the legs in a typical hexapod robot with a rectangular leg arrangement— three by three. It depends on which direction the robot is commanded to go and where the legs are oriented at the point of the command. Again, this is a smaller motor than the vertical motor, as it does not confront forces as great as the lifting forces and, in fact, is the same type of motor used in the extension actuator. From an informational drawing, it also appears to have a 3:7 gear arrangement.

The initial prototypes used external power through a tether, but the design team desired self-contained power in the final model. With some of the lifting capacities in mind and the motors selected, Steve decided to use a 24 volt, 25 AHr aircraft battery to cut down on wire sizes and be able to use lower current driver circuitry. Placed low down in the central cavity, the battery added little weight relative to its power capacity. With the great force capabilities of the Odex in mind, it is amazing that the robot only required 450 watts in active mode and 2 watts in the stand-by mode. For the initial concept demonstrator, the aircraft battery supplied all the power Steve required. Even so, the battery had to be recharged after an hour's use. Later versions used different batteries and these different chemistries brought greater capacities.

Figure 4

With the physical characteristics and overall leg design completed, Steve was now faced with an even larger problem. There was no way that an operator could toggle 18 DPDT polarity reversing switches quickly or accurately enough to be able to control the Odex through a simple series of movements. Just for a leg to move forward for a single step, all three motors must be used. Even for the Odex to turn on its axis, every leg cannot just turn on its swing motor; as the length of each leg changes from a radii to a tangential distance, all of the legs would have to extend a bit just to keep the feet at the same points.

Computer control was required with accurate encoder feedback. This was in the days before microcontrollers existed and only 8- and 16-bit microprocessors were available. As a mechanical engineer, Steve enlisted the help of Robert Drap (Figure 2) to develop the software required and to select the computer hardware. Robert chose the Intel 8086 processor used in the first IBM PCs. The "Odex Operating System," as it was later called, was an embedded type of real time processing package.

Robert had been in charge of software development at NASA's Johnson Space Center (JSC) in Houston, TX. Much of his background had to do with mechanism control — great experience for a new style of walking robot. After a stint at JSC, he did some contract software engineering for Hughes and other clients before making the move to Odetics in 1982. He immediately began working with Steve on the Odex project to develop the gaits and walking algorithms.

Robert explained to me that the Odex Operating System consisted of a core of highly optimized 8086 assembly language primitives. These primitives were "threaded" together to function in a multi-tasking operating system in a single 8086 CPU to control the Odex robot. The core primitives provided the library for all aspects of the software environment, including multiple mains, interrupt servicing, algorithm processing, I/O device drivers, communication queues, as well as an embedded compiler and assembler. When the core primitives were threaded together, the operating system became layered into the application. The total object code size was 48K bytes. The communications link for the remote control was an FM telemetry radio that used FSK modulation with an Intel HDLC communications controller. They used 6809 processors in each leg servo and implemented PID servo loops for the actuator motors.

We have processors these days that are so fast and can address so much memory that designers of today do not have to squeeze every bit of processing power out of modern chips. It was a little bit different 20 years ago for the Odetics team. Much like the NASA Apollo command module and the lunar excursion module computers that operated with as little as 8K bytes of memory, Odex performed its

algorithms with 48 KB of memory in real time on an 8 MHz 8086. There was no remote mainframe or minicomputer involved in algorithm processing, like there was with SRI's Shakey, which I wrote about in the April 2004 issue of *SERVO*. This software impressed many people of the 1980s, including the Smithsonian Institution.

To perfect the required gaits, the team decided to suspend the base and articulators above the floor for ease of observing the different motions. Just as with most hexapod robots built by experimenters today, the Odex uses a tripod gait. To move forward, the robot picks up three legs, which are arranged in a triangle, and moves them forward as the other three legs remain touching the floor and move in a triangle rearward. With computer graphics in color (not bad for 1980s XTs and ATs), it was easy to see if all the articulators were in sync and provided a great debugging tool. They called the three articulator legs that moved forward "translators" and the three load-carrying legs still on the floor "strokers."

When Odex was perfected, it was able to walk through openings as narrow as 21 inches. It could climb steps as high as 33 inches each. It could fold itself into a compact, "tucked" form only 48 inches high by 27 inches wide at the base. At full speed, it could walk as fast as a person's brisk pace. In the "tall" profile, it could raise itself to 78 inches in height. It could actually walk with its articulator legs spread out to 72 inches between leg tips and its height only 36 inches above the floor. It could lift 2,100 pounds with all legs on the floor or carry a load of 900 pounds at normal walking speed. We usually think of the typical industrial robot that I mentioned earlier as being fairly weak for its weight. It might have a light mass at the end effector, but it can move that weight — be it a welding head or paint sprayer — very quickly and accurately. Odex was fast, accurate, and capable of really carrying a very big load.

Needless to say, Odex didn't go up to a set of stairs or the back of a truck bed and just climb in like a giant spider. The operator at his control panel pedestal would enter an algorithm mode for the particular articulator, which was numbered from zero to five for operator identification from a distance. Many demonstration "feats" were choreographed ahead of time by having the operator examine distances, areas, and heights beforehand and dial in articulators and motions on thumb wheels on the control panel. A simple joystick on the control panel was all it took to control the Odex in traversing mode with the direction of the tilt of the joystick corresponding to Odex's motion.

After development and testing over a period of 18 months, Odetics put out feelers for potential users. After seeing demonstrations at various locations, many customers came to Odetics first. NASA was quite interested, as was the Department of Energy, who considered the Odex for hazardous nuclear power plant applications. The Savannah River Labs of the DOE made use of a second version — Odex 2 — and made several significant changes to it. An Odex 3 model that was significantly more powerful with extendible legs was sold to the French CEA — their version of our Atomic Energy Commission. This unit was cable-controlled and also derived its power through the cable.

In my opinion, nothing has yet to come close to the Odetics Odex series in terms of versatile walking robots. Yes, modern computers running 400 times as fast with 10,000 times the memory could allow the Odex to do even more amazing things. New accelerometers, tilt sensors, GPS, and gyros added to a modern package could do wonders. There is no doubt in my mind that these machines would create just as much awe today as they did two decades ago, without any modern additions. Odetics should be commended for striking out on its own to create such an amazing proof of concept machine as the Odexs. **SV**

A Special Thanks

I was particularly disheartened to find out that Steve Bartholet had passed away from brain cancer in 1999. I would like to dedicate this article to his memory. It was his inspiration that brought the Odex to life and he was very cordial to me when, in 1983, he gave his valuable time to show me the two Odexs and talk about their development. Marv Russell, who was Director of Engineering, and Joel Slutzky, then the President of Odetics, also spent a lot of time with me in 1983 and I thank them. I am also indebted to Joel, who is now President of Iteris, Robert Drap, co-developer of Odex (software), Ginny Taylor and Cathy Steger of Iteris, and Tom Bartholet (Steve's brother and also formerly with Odetics) for helping me on this project. These people combed through many files and helped me chase down the people I needed to speak with.

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ASK MR. ROBOTO

by **Pete Miles**

Q. I'm interested in making my robot able to look around and sense temperature — much like you can with a non-contact thermometer — so that it can locate areas that are in sunlight and go directly to them, even if the robot itself is in a shadow or far from the illuminated area.

I haven't been able to find a schematic for these non-contact thermometers to see what device they're based on and they're a little pricey for me to want to hack into. What component is being used for remote temperature detection in these devices and do any sample schematics exist?

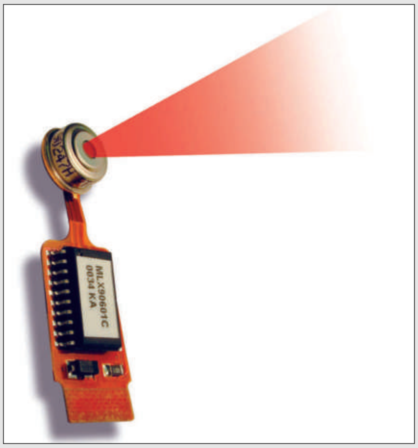
— Ian MacDuff
West Valley City, UT

A. When I first read this question, I was thinking a real simple answer was to put one of those digital thermometers on the top of your robot and have it roam around until it found the warm spot in the house. After rereading the question, this really didn't address the non-contact nature of the question. I, too, thought that this was going to be a very expensive solution, but then I saw the Flashpoint infrared temperature gauge from Duratrax (Figure 1) on the impulse buy page at Tower Hobbies (**www.towerhobbies.com**) for $25.00. I had to get one to play with to see how well they worked. I figured that if the whole unit can be bought for $25.00, then the sensors must be pretty cheap.

Then I found an article in the April 3, 2003 issue of *Electronic Design News* (**www.edn.com**) by Albert O'Grady and Mary McCarthy that showed that all that was needed to make an IR thermometer was a thermopile and an analog-to-digital converter (ADC). They used the MLX90247D thermopile from Melexis (**www.melexis.com**), as seen in Figure 2. A thermopile is a sensor that can generate a small voltage due to a temperature differential on the sensor's membrane. The output voltage is on the order of micro volts per degree Kelvin, so a high precision ADC is needed or an amplifier with a low resolution ADC before attaching it to a microcontroller. The article uses a 16-bit AD7719 ADC from Analog Devices (**www.analog.com**).

Figure 1. Flashpoint infrared thermometer from Duratrax.

Figure 2. Non-contact infrared thermometer module from Melexis (courtesy of Melexis).



I went to the Melexis website to get more information when I found out that they have an exciting robotics event that they sponsor using these sensors. The robot must navigate through a course that has hundreds of cans. Some cans have a candle inside and others don't. The robot must not touch any of the cans that are "hot" and must collect the cans that are "cold." More information about that contest can be found at the Melexis website; just look for their trophy contest.

Also at the Melexis website, I found out that they sell different prepackaged modules

that have the thermopile mounted on a circuit board with circuitry that converts the signals from the thermopile for easy interfacing to a microcontroller. I got the MLX90601EZA-CAA module, since it has both a PWM output and a SPI serial interface. I chose this model because I can use the pulsein command on a BASIC Stamp from Parallax (**www.parallax.com**) to read in the temperature. This module also has an ambient temperature thermometer for correction algorithms. Its relay output is set to trip at 50°C.

The PWM period is 102.4 ms long; thus, the temperature update rate is about 10 Hz for this module. The output temperature (in °C) is shown in the following function:

$$T = \frac{\text{Pulsewidth - 12.8 ms}}{\text{51.2 ms}}\,(140°\text{C}) - 20°\text{C}$$

Figure 3 shows a simple schematic on how to wire this module to a BASIC Stamp 2p with an LCD display. A program that shows how simple these devices are to use is available from the *SERVO Magazine* website at **www.servomagazine.com**

In the end, both the homemade IR thermometer and the FlashPoint thermometer worked the same way. The Melexis thermopiles and modules can be obtained at Digi-Key (**www.Digi-Key.com**). With this information, you should be able to build that sun-seeking robot. There are also a lot of simple schematics showing how to use the thermopile sensors; just use the key word thermopile.

Q. Mr. Roboto, I currently use typical Devantech sonar and Sharp infrared sensor devices in my robotic research. I am working on a bot design that needs similar sensor requirements, but will operate outside much of the time. It does not seem that the typical sonar or infrared sensor would fare well in humid, wet, or very sunny environments. What options does a robot builder have to weatherproof sensors on outdoor projects? Are there other sensors that could be used?

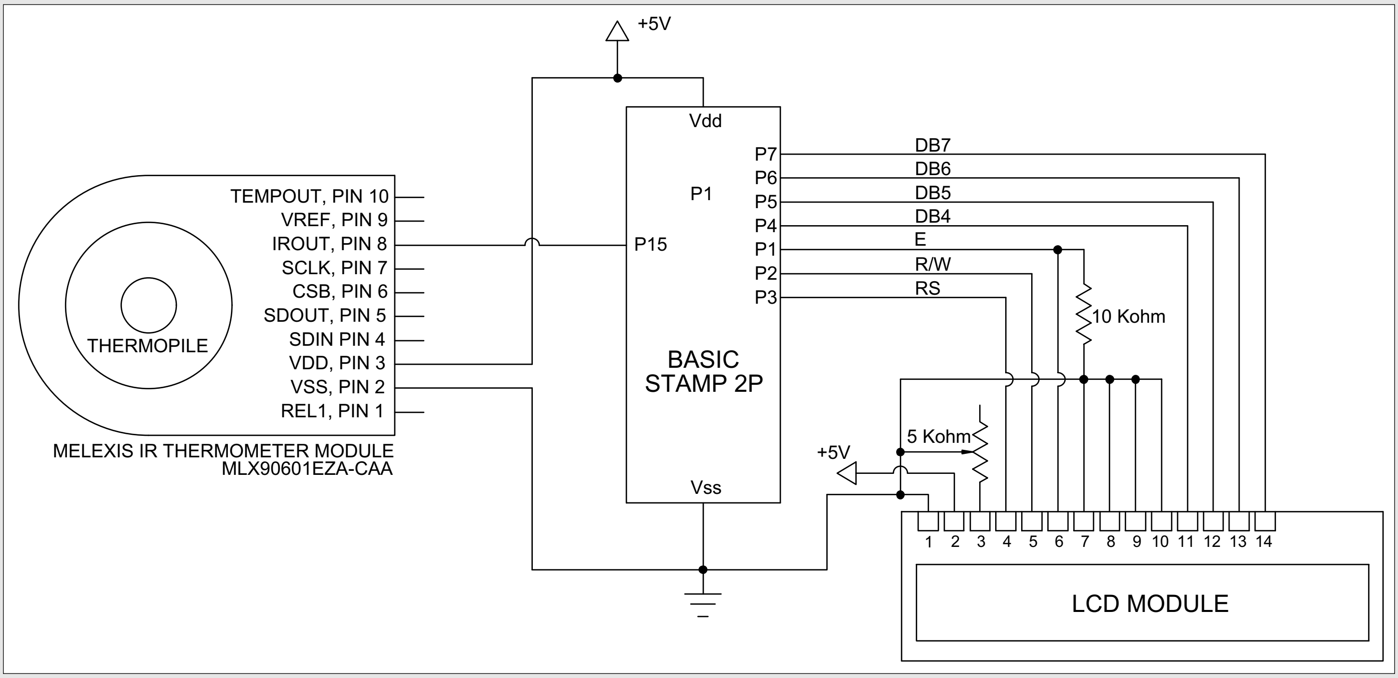
— Michael Faris
via Internet

A. Sensors do react differently between the safe, indoor environments and the hazardous, outdoor environments, but how much do they differ? Well, that really depends on the sensors. For most people, humidity usually only becomes a concern if any condensation forms on the electronic/sensor surfaces that could damage the circuits when moving them between hot and cold environments or when long-term storage in a high humidity environment causes metal surfaces to become corroded or absorb water.

Generally, a sealed enclosure with some desiccant inside to absorb any moisture is all that is needed, but sensor surfaces have to be exposed to the environment in order to work. I have not heard of anyone reporting humidity causing problems with the Devantech sonar and Sharp infrared sensors, but that doesn't mean it won't be a problem for your application.

With ultrasonic sensors, going from an indoor to an outdoor environment will have very little effect on their performance. Though the speed of sound is a function of temperature and is very slightly affected by humidity, the effects are often negligible. The only thing you would want to make sure is that the sensor does not get wet from rain. Placing the sensors inside a tube should help prevent normal rain from getting on the sensor. Make sure there is a small

Figure 3. Infrared thermometer circuit.



drain hole at the bottom of the tube to let any water that gets inside the tube to drain away from the sensors.

If these sensors are not good enough for you, then look at the automotive grade ultrasonic sensors that are used to help with parking alarms and are made by companies such as Valeo (**www.valeo.com**) and M/A-COM — part of Tyco Electronics (**www.macom.com**). Automotive sensors are very hardy in even the nastiest environments.

Infrared sensors are a whole different story. There is very little natural (non-heat related) infrared light indoors, so infrared reflective sensors do a fine job at object detecting and range finding, but outdoors, the environment is flooded with infrared light wherever the sun is shining.

I learned a long time ago that the 40 kHz infrared receiver modules that are commonly used for object detectors do not work in direct sunlight. The sunlight totally saturates the sensors on these receiver modules so that they become useless. In fact, a strong flashlight will blind these sensors. Since I had no outdoor experience with the Sharp GP2xxxx class of sensors, though, I decided to conduct a set of experiments to see how well they work.

I placed a three-foot square piece of 1/4 inch thick semi gloss expanded PVC up against a wall and measured output voltages from a GP2D12 short range and a GP2Y0A02YK long range analog sensor. The test consisted of measuring the voltage at distances from two to 40 inches with the sensor pointing straight at the plastic sheet. The test was done both indoors and outdoors. The sunlight was striking the plastic at about a 45° angle, so it was fully covered with direct sunlight and no shadows and the sensor itself was fully exposed to direct sunlight. The temperature outside was about 75°.

The results from these tests are shown in Figure 4. The GP2Y0A02YK sensors showed very little effect from the sunlight at any range. The only difference was that the output voltage was about 0.1 volts higher for all of the outdoor tests. The shape of the plot is almost identical. This shows that this sensor can be used both indoors and outdoors without any recalibration efforts.

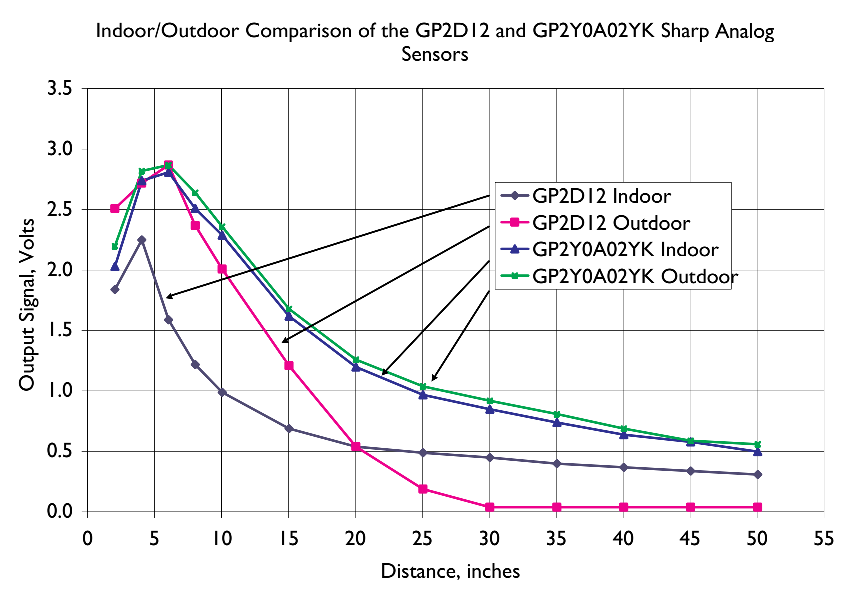
The GP2D12 sensor, on the other hand, showed a very high output voltage for short ranges; in addition, the slope of the indoor and out door plots are different and, when the range exceeded 20 inches, the outdoor output voltage quickly dropped to zero volts, whereas the indoor sensor still provided measurable results.

The results from these tests show that this sensor would require significant software recalibration efforts to use it when changing from an indoor to an outdoor environment. Most likely, this sensor should be replaced with the GP2Y0A02YK sensor if outdoor use is planned. What is interesting is that the electronic circuit boards for both of these sensors are identical. The only thing that is different is the physical package and optic selection.

Like with the ultrasonic sensors, they shouldn't be allowed to get wet. Placing tubes around the sensors will help protect them from the environment. One of the nice things about using optics is that you can place the sensor behind a clear piece of plastic that is used to prevent any rain from getting on them. Just make sure you don't scratch the surface of the plastic in front of the sensor.

The bottom line is that these sensors can be used outdoors. All that is required is to select the proper Sharp sensors and protect them from getting wet. If more range and/or reliability is needed, then look at the industrial/contractor grade laser distance measuring systems. Keep in mind that these laser distance measuring systems should not be used in the general public due to eye safety concerns regarding the laser.

Figure 4. Indoor/outdoor comparison of the Sharp GP2D12 and PG2Y0A02YK analog sensors.



Q. Mr Roboto — Help! I'm very much interested in learning (as a personal hobby) Java, even without any previous technical experience using the software. I want to learn it in order to LEGO Mindstorms projects, particularly the "chess playing robo arm" model. How should I go about learning Java? Is there a beginners' group I should hook up with? Should I learn other PC language first before Java?

Thanks. I am glad your "helpdesk" exists.

— Carlo C. S.
via Internet

A. The best way to learn how to use Java with the LEGO Mindstorms RCX bricks is to just start programming with it and see what happens. Probably the easiest way to learn how to do this is get a copy of either *Core LEGO Mindstorms Programming: Unleash the Power of the Java Platform* by

Brian Bagnall or *Programming LEGO Mindstorms with Java* by Dave Laverde. Then program your LEGO Mindstorms set with every one of the examples in their books. As you go along, make some small changes to their examples and see how this affects the robot and the program. There is no better way to learn than good, old-fashioned, hands-on experience.

If you are interested in learning how to program a microcontroller with Java so that you can make a robot, then take a look at the Javelin Stamp from Parallax (**www.parallax.com/javelin/index.asp**). They have a pretty powerful Java programming environment with lots of complete working examples. All of their documentation can be downloaded from their website for free. One of the things that I really like about the Parallax company is that their documentation is designed to teach people how to get started.

Another great place to learn about the LEGO Java operating system for the LEGO Mindstorms is the LeJOS website (**http://lejos.sourceforge.net**). There, you can download the latest software and utility revisions, applications, see other people's robot projects, download the latest tutorial for the language, and find useful links to other LEGO-Java websites. In the end, though, the best way to learn how to use Java to program the LEGO Mindstorms is to start programming with it.

Q. Are there any low cost, hobbyist grade lathes that can be used to make small metal parts? If so, can you help me find more information on them?

— Bill
Phoenix, AZ

A. About two years ago, I needed some custom hubs for my 3 kg sumo project. These aluminum hubs needed to hold a 16 tooth, #25 chain sprocket for an R/C car racing wheel onto a 6 mm diameter gear motor shaft. So, I made up some drawings and sent them out to some local machine shops to get quotes to have them made. I only needed four, but I decided that I should have some spares, so I asked for a total of eight to be made. The quotes I received ranged from $600.00 to $800.00 for the set. This was a tad bit more than I was willing to spend. In fact, it was more than the rest of the robot.

Then I remembered an advertisement that I saw in a Harbor Freight flyer for a 7 x 10 mini lathe for $330.00 (maximum seven inches in diameter with 10-inch long parts). For this price, I could buy one of these lathes, make the parts myself, save a few hundred dollars, and — best of all — I would get to keep the lathe to make other kinds of parts.

A search on the Internet using the key words "mini lathe" showed that these mini lathes are very popular and that there are hundreds of sites that are dedicated to showing off the really amazing things that can be made with them. Most of these lathes are manufactured by the same company — the Sieg Machine Tool Factory (**www.seigind.com**) in Shanhai, China — and are sold under different brand names and in various paint colors.

Company	Size	Website
MicroMark	7 x 14	**www.micromark.com**
Grizzly	7 x 12	**www.grizzly.com**
Homier	7 x 12	**www.homier.com**
Harbor Freight	7 x 10	**www.harborfreight.com**
Enco	7 x 10	**www.use-enco.com**
Taig Tools	4.5 x 9.8	**www.taigtools.com**
Sherline	3.5 x 8	**www.sherline.com**

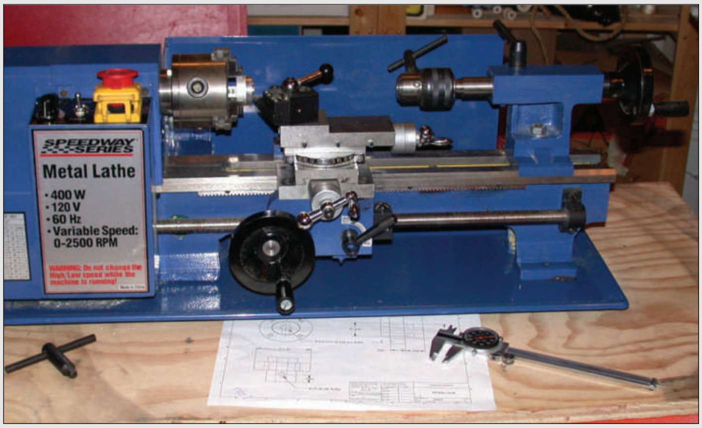
Table 1. Various miniature lathe retailers and manufacturers.

While searching the net, I stumbled across a great website — the Mini Lathe website (**www.mini-lathe.com**). This website is dedicated to providing lots of beginner information on these types of a lathes — including reviews on different models, how to get started, and many useful tips on how to maintain and use the mini lathe.

From there, I found a link to the Little Machine Shop (**www.littlemachineshop.com**). This is a great, one-stop shopping place to get all the tools you will need to use with the mini lathe. I bought all the tools for my lathe based on the recommendations from the Mini Lathe website and the Little Machine Shop.

Table 1 shows a short list of several different types of these miniature lathes. The top five lathes are different versions of the lathes made by Sieg and the bottom two are completely different lathes that are very popular in the hobbyist community. Since I was planning on buying all of my tooling from the Little Machine Shop, I decided to purchase a bare bones 7 x 12 lathe from Homier for $299.00 (Figure 5). So far, I have had no complaints about my little lathe, though my wife has had a few when I brought it in from the garage and made parts on the dining room table. SV

Figure 5. Mini Lathe from Homier with the Phase II quick tool changing post from the Little Machine Shop.



EVENTS CALENDAR

Send updates, new listings, corrections, complaints, and suggestions to: **steve@ncc.com** or FAX **972-404-0269**

The busiest months of the year for robot competitions have passed, but don't worry — there are still plenty of events on the way. There are several Robot Soccer events coming up soon, as well as events for underwater robots, flying robots, micromouse robots, and any other type of robot you might be interested in.

— R. Steven Rainwater

For last minute updates and changes, you can always find the most recent version of the complete Robot Competition FAQ at Robots.net:
http://robots.net/rcfaq.html

June

4-6 **RoboJoust**
Las Vegas, NV
Another radio-controlled vehicle demolition derby.
www.robojoust.com

5 **Argentine Championship Robot Soccer**
Buenos Aires, Argentina
Middle League SimuroSot robot soccer
www.exa.unicen.edu.ar/cafr2004/

6 **PDXBOT**
Smith Center Ballroom, Portland State University
Portland, OR
Lots of events, including mini-sumo, micro-sumo, Japanese sumo, line following, walkers, and a talent show.
www.pdxbot.org/

12-14 **AUVS International Ground Robotics Competition**
Oakland University, Rochester, MI
An autonomous ground vehicle must navigate an outdoor obstacle course within a prescribed amount of time while staying within a 5 mph speed limit.
www.igvc.org/deploy/

19 **UK National Micromouse Competition**
Technology Innovations Center, Birmingham
London, UK
Robot mice strive to win the coveted brass cheese.
www.tic.ac.uk/micromouse/

25-27 **MATE ROV Competition**
University of California (UCSB), Santa Barbara, CA
Student-built ROVs must locate and retrieve objects of varying sizes and shapes.
www.marinetech.org/rov_competition/

27-Jul 4 **RoboCup Robot Soccer World Cup**
Lisbon, Portugal
This event includes the Soccer Simulation League, Small Sized Robots, Mid-Sized Robots, Four-Legged (AIBO) Robots, RoboCup Junior, and the Humanoid Robot League. The overall goal is to field a team of robots that can beat the world's best human team by 2050.
www.robocup.org/

July

17 **DPRG Table-Top Robot Contest**
The Science Place, Dallas, TX
Mini-robots compete on table-top sized courses in line-following, sumo, and other events.
www.dprg.org/competitions/

19-24 **AUVS International Aerial Robotics Competition**
Dismounted Battlespace Battle Lab
Fort Benning, GA
A fully autonomous, 3 km challenge to locate a particular structure, identify openings in it, fly in or send in a sensor to find one of three targets, and relay video or still photographs back to the origin in under 15 minutes.
avdil.gtri.gatech.edu/AUVS/IARCLaunchPoint.html

19-23 **K'Nex K*bot World Championships**
Las Vegas, NV
Three types of events are included: two-wheel drive autonomous K*bots, four-wheel drive autonomous K*bots, and radio-controlled Cyber K*bots.
www.livingjungle.com/

25-29 **AAAI Mobile Robot Competition**
San Jose Convention Center, San Jose, CA
This event has several challenges. Robots must navigate the conference center in the "Robot Challenge." They must locate injured humans in "Robot Rescue" and act as servants to humans in "Hors d'oeuvres Anyone?"
www.aaai.org/Conferences/National/

25-29 **Botball National Tournament**
San Jose, CA
Held in conjunction with the National Conference on Educational Robotics and timed to coincide with this year's AAAI convention.
www.botball.org/

28-Aug 1 **AUVS International Undersea Robotics Competition**
Autonomous underwater robots must locate a target at the bottom of the test arena, deposit a market on the target, and proceed to a recovery zone to surface.
www.auvsi.org/competitions/water.cfm

(No confirmed August events)

September

3-6 **DragonCon Robot Battles**
Atlanta, GA
Radio-controlled vehicles destroy each other at a famous science fiction convention.
www.dragoncon.org

6-7 **RoboCup Junior Australia**
Queensland, Australia
There are over 600 RoboCup Junior teams in Australia. Regionals narrow this number down to about 200 teams that will compete at the University of Queensland to see who's the best at building LEGO-based, autonomous soccer robots.
www.robocupjunior.org.au/

11 **ABU Robocon**
Seoul, KOREA
Autonomous robots must build a bridge and then move objects across it.
www.kbs.co.kr/aburobocon2004/

October

8-10 **Robot Fighting League National**
Herbst Pavilion, Fort Mason Center
San Francisco, CA
Radio-controlled vehicles destroy each other in San Francisco.
www.botleague.com/

9-10 **RoboMaxx**
Grants Pass, OR
Includes a range of events for autonomous robots, including maze solving, 3 kg sumo, mini sumo, micro sumo, and nano sumo.
www.sorobotics.org/RoboMaxx/

21-23 **Tetsujin**
Santa Clara, CA
SERVO Magazine's weight lifting competition among powered, articulated exoskeletons offers an event incorporating the technology of the future. The event is held in conjunction with RoboNexus. See the information on pages 4 and 5 of this issue for more information or visit the website.
www.servomagazine.com/tetsujin2004/

22-24 **Critter Crunch**
MileHicon, Marriott Southeast, Denver, CO
The Denver Area Mad Scientists were pitting autonomous and remote-controlled robots against each other long before commercial events like BattleBots and Robot Wars.
www.milehicon.org/

27-31 **FIRA Robot World Cup**
BEXCO, Busan, Korea
All the usual categories of robot soccer, including humanoid, single, team, khepera, and others. See the website for details.
www.fira.net/

MENAGERIE

Send us a high-res picture of your robot with a few descriptive sentences and we'll make you famous. Well, mostly. menagerie@servomagazine.com

SWAT Bot

Zack Beiber, Monrovia, CA

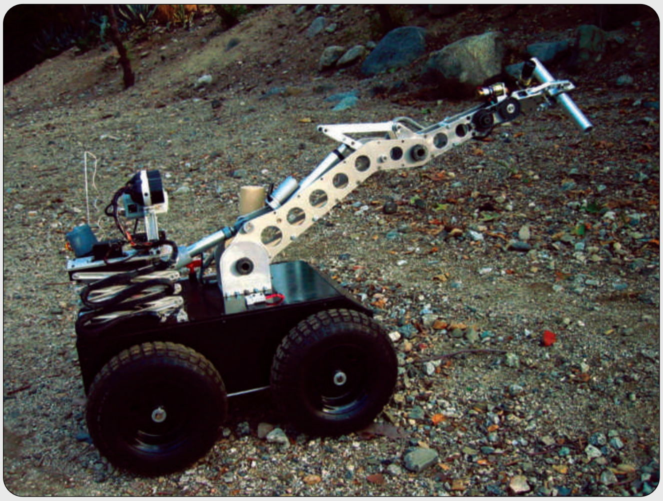
SWAT Bot weighs in at 150 pounds and its speed is around 5.8 feet/second (or about 4 mph). The arm — when fully extended — can lift about 20 pounds and over 50 pounds when it is in other positions. The robot can open doors and climb curbs. The lower frame-mounted IR camera can see in total darkness and can peer under cars. The zoom camera can read a license plate from several blocks away. The halogens are used to blind a suspect in a doorway while SWAT members change position. The robot is also used to deliver throw phones, food, water, and tear gas.

The robot has already participated in a SWAT training scenario where a terrorist overtook a bus full of hostages. The robot performed flawlessly for almost four hours (mostly standing-by). It was used to look into the windows of the vehicle so the officer could describe the terrorist to the team. It was also used to deliver food and soda and to look under the bus for bombs.

This robot took me about 300 man hours to build and over $12,000.00 in parts and components. The robot is now a member of the West Covina, CA Police Department and SWAT team.

www.themachinelab.com

Channels of control include: left and right drive, shoulder, elbow, wrist up and down, wrist rotate, gripper open and close, 30 inch scissor camera lift up and down, pan/tilt/zoom for two cameras (one remote zoom 200X and one IR illuminated), and halogen lights on and off.



CUTTING EDGE ROBOTICS

Part 6: Flipper — With a Twist

by John Myszkowski

We have been very busy little workers — cutting metal, building robots, and learning all about the extreme basics of robotics. By now, you should have a robot that can fight in a mini-sumo ring, a robot that can walk around on peg-legs, and, now, a robot that will be able to fight in a combat arena for its very survival. May the best robot win.

To the Bat Poles

Last month, we were in the middle of adding the flipper-scoop to our combat robot and, this month, we will put it all together. We need to complete the flipper assembly and add a remote control to make the Cutting Edge (C. E.) Robot into a battle-ready fighting machine that will fit in the ANT-weight category. We will add the "Twin Peaks" wheel protectors and even build a simple spinner for the back end. It's going to be a busy month, so let's cue up that old Batman song and get to work (Figure 1).

The Base-icks

The most critical of the flipper assembly is the base; it's also the hardest part to make. It is the same part which will also mount the articulated manipulator (ARM) for the C. E. robot in a future installment. The base holds an R/C servo that actuates the flipper and functions as a balancing hinge on the opposite side of the servo actuator shaft. The base is designed to fit on the C. E. Robot chassis, but it will just as easily fit on top of the popular Mark-III robot (Figure 2).

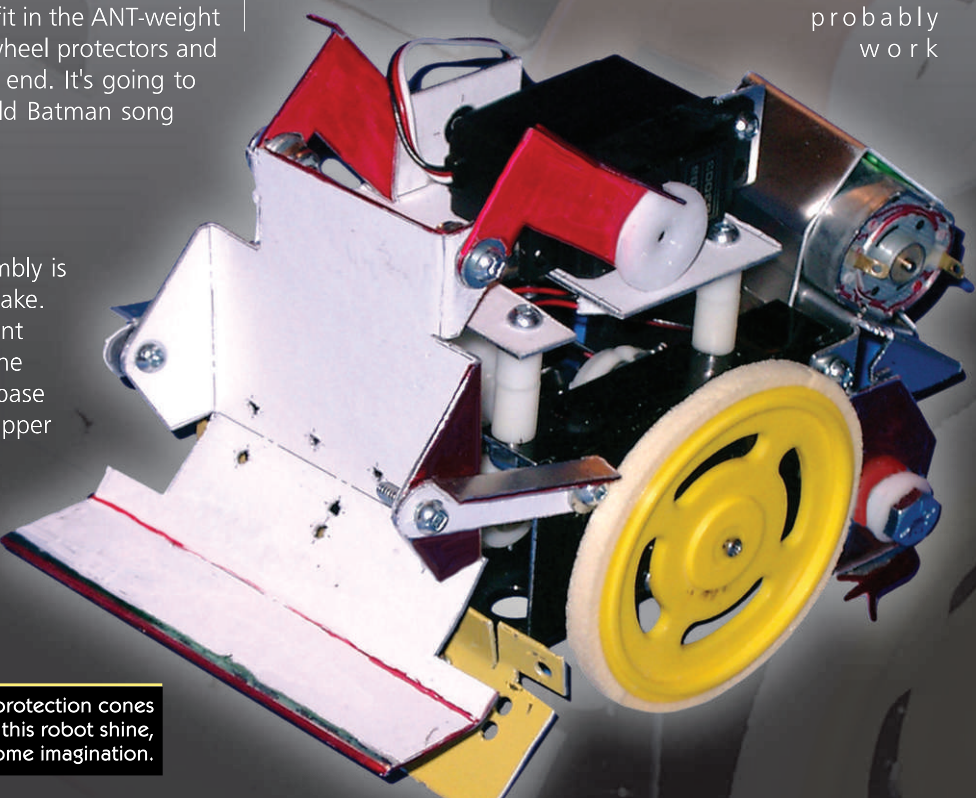


Figure 1. Mostly finished. The wheel protection cones and some paint will make this robot shine, but for now you need to use some imagination.

The servo mounting tabs have oversized mounting holes to allow for small misalignments. It is easy to get the tabs twisted while bending them, but, at the same time, it is just as easy to straighten them out with a small pair of pliers (Figure 3). The critical alignment is between the servo actuator shaft and the hinge, but the oversize servo mounting holes allow us to slide it around until it is on the same axis. For the same reason, the four chassis mounting holes are also slightly oversized.

The height of the mounting distance between the base and the robot chassis is very important and should be as close to 0.75 of an inch as possible, but don't fuss too much. I have spacers that are 0.85 inches long and work well, so it will probably work

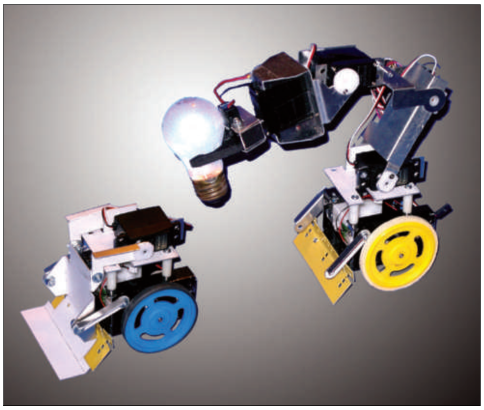


Figure 2. The base plate will accommodate the flipper-scoop, as well as our future addition, the ARM.

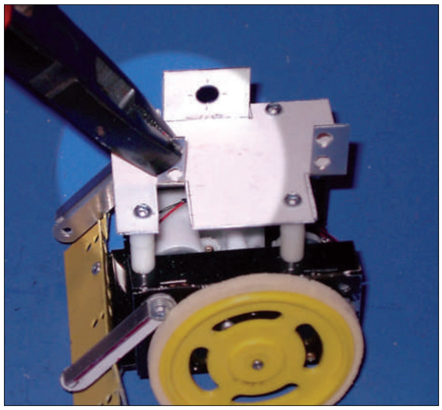


Figure 3. Easy to brake and easy to fix. The base can be persuaded to comply by twisting its ears with a pair of pliers.

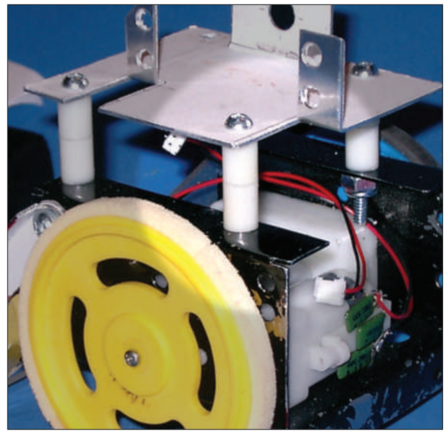


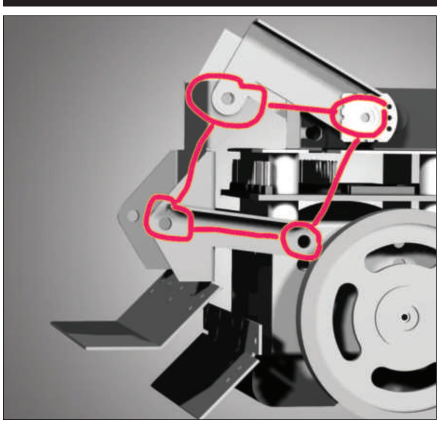
Figure 4. The plastic spacers are just the right height, even after installing the PCB.

with 0.65 inch spacers just as well (Figure 4).

The Vita Link

Just as with our Peg-Leg walker, the power to the flipper and the direction of movement is transferred through a set of four links. The main link is attached to the servo horn and acts as a servo arm, which moves the flipper-scoop up or down. The bottom link —the one directly below the main one — keeps the flipper-scoop parallel to the ground and the robot's chassis by forming a parallelogram (Figure 5). The remaining two links — on the robot's opposite side — keep the flipper-scoop from twisting and binding.

Figure 5. The parallelogram configuration of the linkages allows us to lift the scoop while keeping it parallel with the ground.



The Collection

Use the photos as your guide for proper positioning and sequencing.

First, attach the bottom two links to the robot chassis, as shown (Figure 6).

Position and attach the servo base plate to the robot chassis. Make sure it sits square to the sides before tightening the screws.

Attach the top two links to the top two mounting tabs of the flipper-scoop (Figure 7).

Now, attach the bottom two links to the bottom set of mounting tabs (Figure 8).

Place the R/C servo within the mounting brackets, as shown. Place mounting screws in the mounting holes, but do not tighten them yet (Figure 9).

Attach the top two links to the servo and the hinge.

The servo should be in its neutral (starting) position at this time. If it is not, then apply power to it until it returns to neutral and stays in that position. It should only take a moment to rotate the servo horn to neutral.

The robot should be placed on a flat surface with the flipper-scoop down in its resting position.

Place the servo horn over the servo shaft, inside the linkage mounting hole. Use a small screw to hold the servo horn securely on the link (Figure 10).

If you have a way of testing a servo, then do so now. The movement should position the servo horn on the same axis as the hinge. Tighten the servo mounting screws.

Figure 6. The bottom two links are attached first.

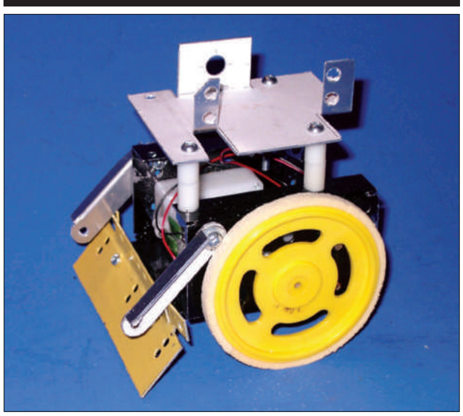
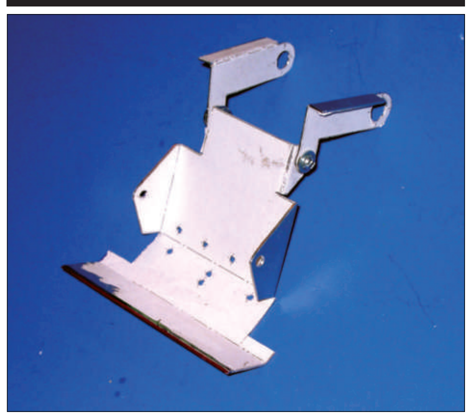


Figure 7. The top links are attached to the scoop first.



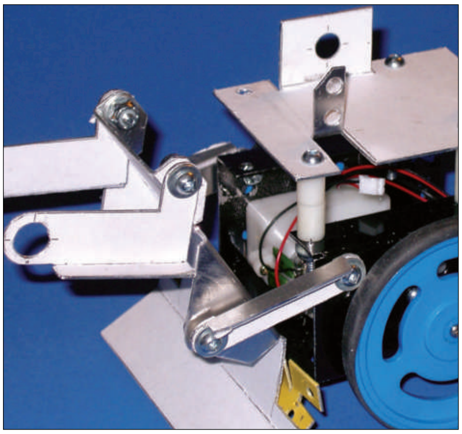


Figure 8. The bottom two links are now connected to the scoop.

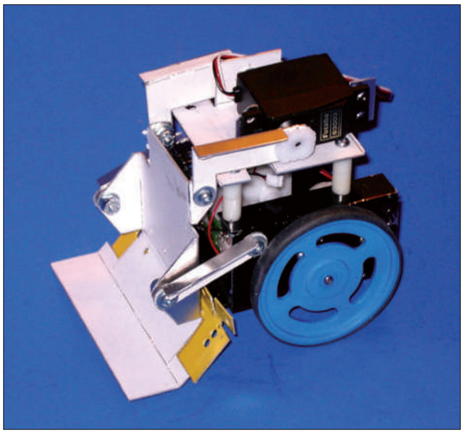


Figure 9. The R/C servo goes on next, but do not tighten the screws.

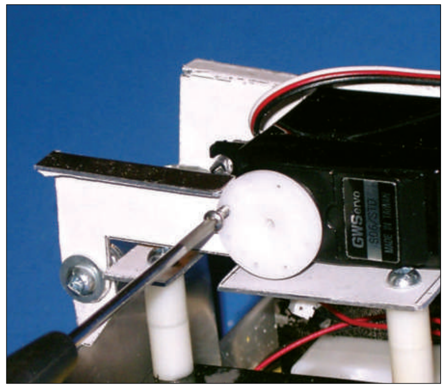


Figure 10. The servo horn is used to connect the R/C servo shaft to the scoop mechanism. Use a small screw to fasten the two parts together.

At this point, your flipper weapon should be fully operational (Figure 11).

Twin Peaks I ... Stable Relations

With the flipper finished, you probably want to try it against a worthy adversary; that's understandable. After your first battle, you will soon realize that you need some kind of stabilization or at least something to keep your robot from being flipped on its side. As with anything else, there are many ways to achieve this goal.

We can add "active" or "passive" stabilization to our robot. The active version is too complex for this month's installment, but we may revisit it in a future article. At this time, we will focus on simplicity. Our design of the day calls for passive stabilization. It is much easier to implement and is cheap; in this case, cheap is good.

Twin Peaks II ... Madonna Was Here

You may think it's simple, but reality is always different. What we need to make is two metal cones. Even though it sounds easy, it's not as easy as making a cylinder out of paper. Okay, I may be exaggerating just a little, but you may need to practice on paper first. The left and right templates are identical, so, if you make one, the other will be even easier (Figure 12).

When complete, you should have in your hands two nice and shapely cones, ready for mounting. Decoration is always well-received and highly recommended, as it adds personality and a devoted following. Tassels might work ... (Figure 13).

Remotely Together

Let's leave the construction behind us and take control of the robot. Until now, we have been using a variety of autonomous devices for controlling the C. E. Robot, but, in order to use it in the battle arena, we will need to control it remotely. If the purpose for your robot is not combat, then you do not need to limit yourself to RF (radio frequency) devices. IR

Figure 11. The finished flipper should now be fully operational.

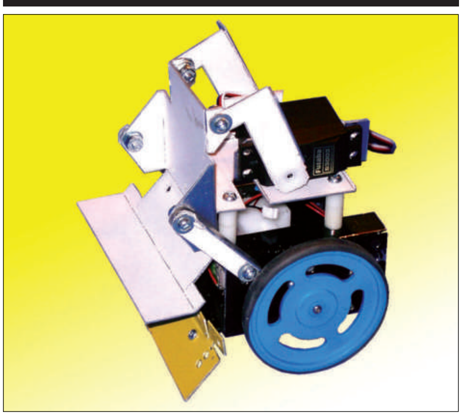


Figure 12. Template for the "Twin Peaks." Use any material that is handy and will do the job. Even the thinnest aluminum sheet will do the trick.

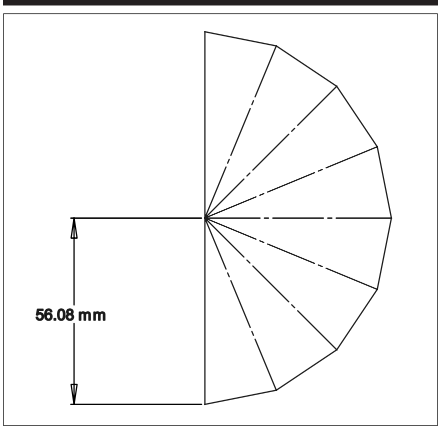


Figure 13. The tassels make anything look good.

References

Check out the following Internet links. They are all related to the Cutting Edge projects.

Supplier and Information Web Links:

www.novarobotics.com
(C.E. Robot parts and custom CNC work.)

www.hobbyengineering.com
(GM2 motors and many different robot components.)

www.1sorc.com
(Sumo-11 boards and information.)

www.basicx.com
(Home of the BX-24.)

www.cuttingedgeprojects.com (This is the place to check for more projects.)

www.robotgames.ca
(Robot information and competition.)

www.robotgames.com
(Robot information and competition.)

www.solarbotics.com
(Source of GM2 motors and other robot parts.)

www.barello.net
(R/C robot controllers.)

www.bugnbots.com
(Robot parts, GM2 motors, PCBs, etc.)

www.junun.org
(Mark-III robot, R/C servos, and other useful robot parts.)

www.avrfreaks.net
(What AVR is and everything you ever wanted to know about it.)

www.ridgesoft.com
(Java support for the Sumo-11.)

www.botleague.com
(Home of the Robot Fighting League and your gateway to the world of robotic combat.)

www.servocity.com
(R/C equipment, R/C servos, servo components, and useful information.)

Yahoo User Groups:

http://groups.yahoo.com/group/CuttingEdgeProjects

http://groups.yahoo.com/group/MiniSumoMarkIII/

http://groups.yahoo.com/group/Sumo11users/

http://groups.yahoo.com/group/tabrobotkit

(infrared) controllers have been more popular lately, with their newer and more powerful emitters and receivers (Figure 14).

Battlefield (Infra) Red

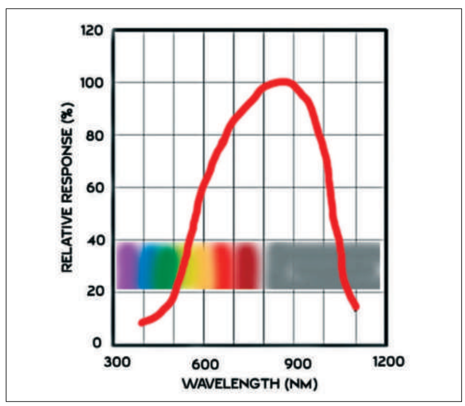
IR is much more cost-effective and does not fall under any governmental regulation (yet); this makes it the most accessible remote control technology. You can pick up a brand new, universal TV remote for under $5.00 at many retail outlets and I can see this falling to the $1.00 level very soon. The buttons on the remote can be relabeled with arrows instead of numbers and then you will have a remote control for your robot. You can even have function buttons for activating preprogrammed actions.

The receiver end is even simpler. If

Figure 14. A collection of remote control devices. All have their place in the robotics hobby.

Figure 15. The receiver end of an IR (infrared) control system. Just about any light sensitive device can be used. Device specs are readily available on the Internet.

Figure 16. A silicon semiconductor as used in an IR receiver is actually sensitive to a lot more than just the IR range. It is quite useable within most of the visible light range, although it may need extra amplification closer to the blue end of the spectrum.



you already have a microcontroller for your robot, then the only additional components needed are an IR sensor and some software to translate the incoming signals (Figure 15).

You can go all out and get a receiver module that will provide a lot more sensitivity and extraneous light filtering or you can simply use a photo transistor hooked up directly to the micro. You will also need a hand-held controller.

IR-ritating Behavior

Not all IR controllers can be used for competition and you certainly can't use it for both opposing robots. The biggest problem with using two IR remotes is their identical carrier frequency or the color of the light itself. The simultaneous transmissions from the two IR emitters tend to swamp each other out and, at the very least, they will interfere with each other. IR remotes are not designed to coexist simultaneously with others and that presents a bit of a challenge.

In an RF remote system, there are two components which make it possible for two or more sets to work simultaneously:

- First is the tight, crystal-controlled frequency at the transmitter.

- Second, the receiver contains a very tight band pass filter, which is also crystal-controlled. This tight frequency control makes multiple channels possible.

We can add extra channels to the IR systems in a similar way. The peak sensitivity of a semiconductor light sensor is in the IR range, but it is also sensitive right into the visible red and even green ranges (Figure 16). By installing different band pass filters on the emitters and receivers, we will be able to add more channels. The IR emitter can be replaced with a red or green LED and the receiver can be fitted with a similarly colored light filter. The old 3D glasses have nice red/green or red/blue filters that will work well in such applications.

Clear Choice

If the glory of war is on your mind and you're just itching to prove your superior technology and fighting skills, then you will need to look into the RF remotes (Figure 17). Some competitions do allow IR remotes, but most will only accept certain types of RF controllers. If you plan to grow into progressively larger robots, then it makes a lot of sense to invest in a good, RFL recommended controller and reuse it for all your new projects. Such an investment is well worth it.

Shelf Motivation

Off-the-shelf, ready-made components are very often hard to resist — especially when it costs more to build them from scratch. If you want parts in your hands quickly, you need to get them from a good source. I have located a couple of great sources of robotics-related parts that you may wish to check out (Figure 18).

- Larry Barello (**www.barello.net**) is a very knowledgeable professional who has been designing and selling a number of robotics devices from his website for awhile. His website is full of useful and reliable information dealing with controllers, signal converters, and sensors.

- Tim Rohaly (**www.junun.org**) is a long-time robotics enthusiast who operates a small business selling

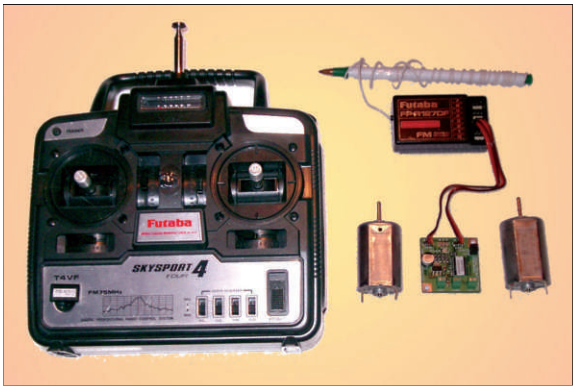


Figure 17. An RF remote control system. It uses a standard R/C transmitter and receiver. The output of the receiver is translated to the regular DC motor "language" by an ANT100 controller (as sold by Larry Barello).

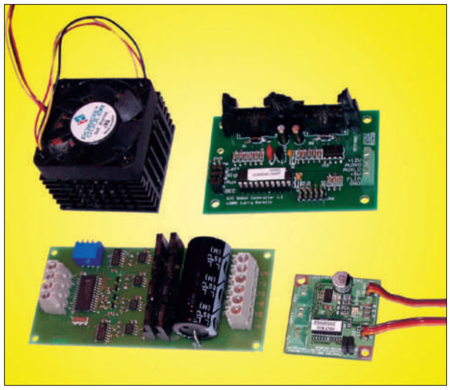


Figure 18. Here are a couple of controller boards that translate the R/C pulses into high power DC motor signals. They can be purchased from Tim Rohaly or Larry Barello.

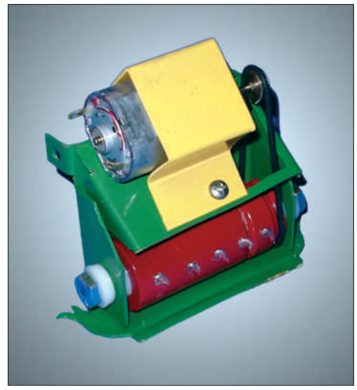


Figure 19. The assembled "Tail Spin" — our spinning weapon. The power is dished out to the enemy via the spinning "teeth."

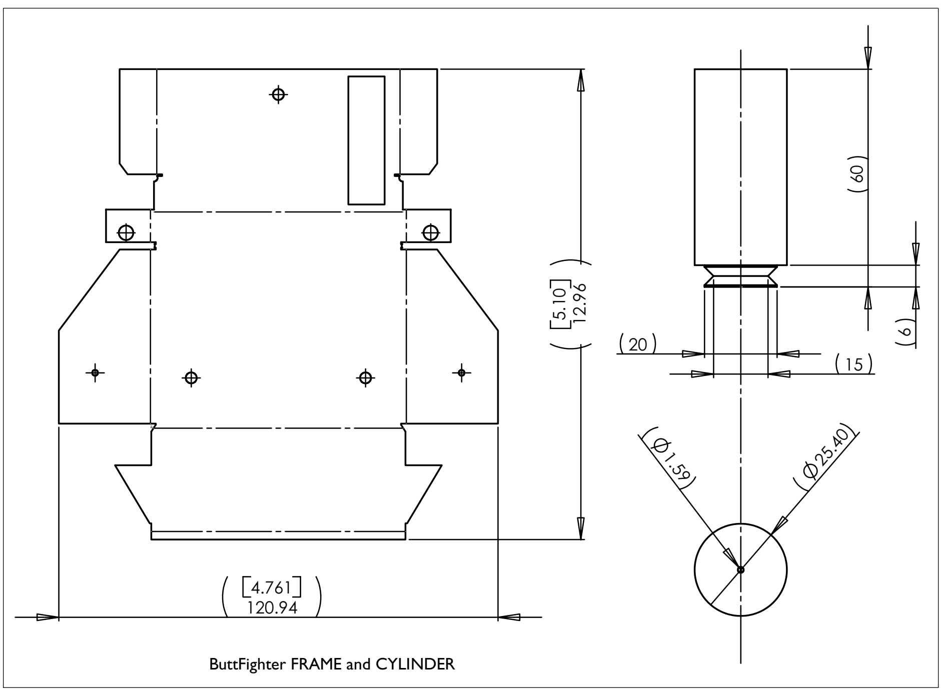
components for other robotics enthusiasts. Among many robot parts, he has a couple of items that will also fit the description of a good controller.

R/C signal to high power DC motor conversion and controllers are some of the parts you will find in these places. What is also amazing about the above sources is the full documentation available online. Check out these two places before you go anywhere else.

Violence Begets Violence. Oh, Well!

Alright already, I'm getting to it. I will now describe a simple, offensive weapon that just might let your cute, little robot win a match or two. We are going to make the spinner of death, the drum from hell, the rotating cylinder of evil, the toothed wonder, the ... Ah, what the heck, we will make the weapon that your opposition dreads: Tail Spin, a spinning drum that will disintegrate the enemy robot just by touching it ... Far fetched?

Figure 20. The template for the "Tail Spin" is meant to serve as a guide only. The dimensions are correct, but you will probably want to build something bigger and better.



Twist of Power

This may not be as unbelievable as you might think. A spinning weapon's effectiveness depends on its stored kinetic energy and our spinning chunk of steel has a lot of potential for mischief. The key here is mass and speed. The faster the mass is spinning, the more power it will take to stop it. If we can concentrate all this kinetic energy in a small spot, we will have an unstoppable "tooth" (Figure 19).

Our spinner is a metal drum that has small, sharp teeth through which all the stored kinetic energy will be released upon contact.

To conserve space, the motor may be mounted inside the drum, but that would present a power supply problem. On the other hand, we can use an externally mounted, smaller DC motor and a drive belt to power the spinning drum. A small, but really fast motor for your weapon that has enough power to start the heavy drum moving will take some time to spin up to full speed. It is like charging a kinetic capacitor; the higher the speed, the

higher the kinetic energy (Figure 20).

Capacity for Mayhem

The teeth of the spinning drum are like the capacitor terminals that transfer the stored energy upon contact. For obvious reasons, the teeth need to be strong and securely attached to the drum to be able to withstand the shock. All the kinetic energy will be focused through the first contact, so the power will be greatest at that point. To emphasize that last point — the contact area of the teeth should be as small as is reasonable in order to concentrate the power.

Good Behavior

With a high speed motor, the teeth have a good chance of being loosened or worse — broken off. That would be bad for the weapon's effectiveness, as well as presenting a safety concern. It would be wise to design a tooth that is secure, strong, and replaceable, if necessary.

A small, short, hex-head bolt is a good choice for the tooth and the threads can be glued in with a thread-lock adhesive.

The major source of misbehavior is friction between two parts — one wants to move and the other wants to stay. A small motor, whether it is fast or slow, has very little torque and any friction quickly adds up to keep it from turning. Careful bearing design will allow you to use a smaller motor, but, in most cases, you will be forced to use a larger motor and higher current to keep the mass spinning. My quick solution uses a larger DC motor, but you may replace the massive load with a thin blade.

One of the things I love about hobby robotics is the relatively small scale and the ability to make quick changes when necessary. I showed you a way to make and mount a spinning weapon and it even works when assembled with care. You may use my templates or you can design your own variation and make it even better than my spinner. Just don't forget to have fun doing it.

Parts

All the parts are standard screws, washers, nuts, etc. These can all be found in your local Home Depot or other hardware store.

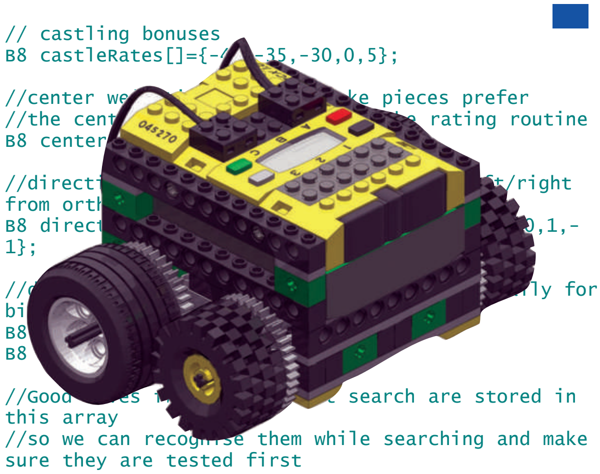
The R/C equipment — including the servos and the remote controller — can be bought at any hobby store or at Servo City (**www.servocity.com**).

Deviants, Variants, and Mutations

We have already covered a simple robot chassis, wheels, legs, scoops, controllers, and now an evil, battle-starved bot. It is a good time to start thinking of more peaceful alternatives again, so let's turn our swords into plows and convince our robots to do something useful. During peaceful times, we can discard the spinner, but the flipper-scoop can be reused for more benefical tasks.

In the next month's installment, we will cover the gripping story of the C. E. ARM. We will finally start work on the manipulator end of the robot. It's the hand that rocks the robot, the grip of power, the short hand, or just the Gripper, for short (Figure 21). **SV**

Figure 21. Coming to grips with the next month's installment — "The Gripper."



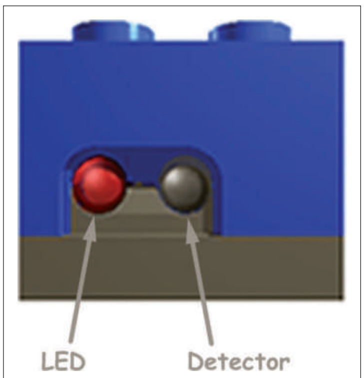
LESSONS FROM THE LABORATORY

A bi-monthly column just for kids!

— PART 3 —

Seeing the Light: Introducing Light Sensors

by James Isom

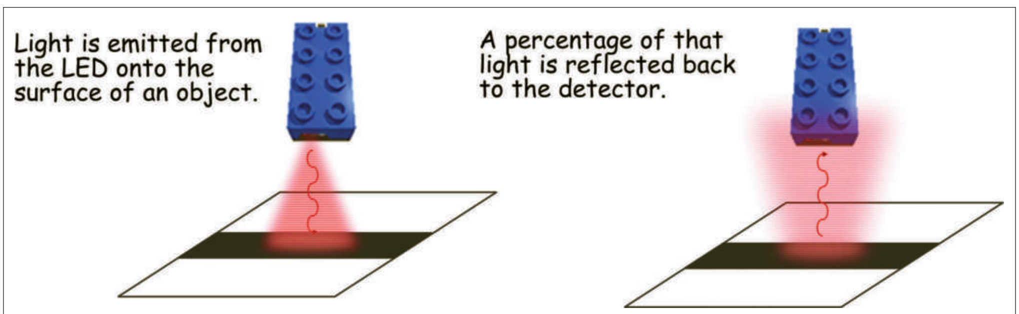


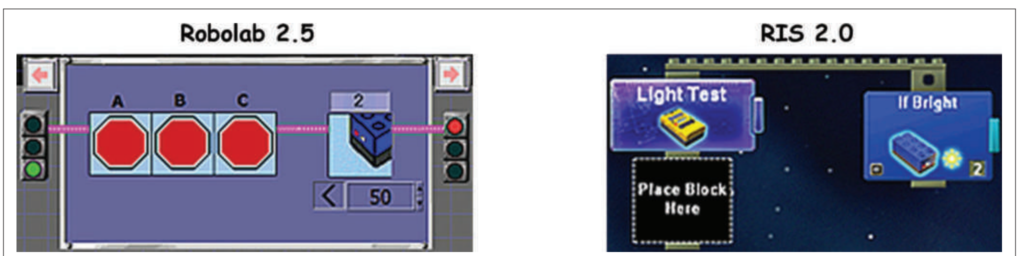
Light sensors can be an important aid to navigation and a great way for your robot to learn about its surroundings without reaching out and touching it. Let's learn a little about how the light sensor works and find some simple things we can do with it.

You will notice that, at one end of the sensor, there are two round objects. The one on the left is a Light Emitting Diode (LED) and the one on the right is the light detector (really a phototransistor).

Assuming that the sensor remains the same distance from the object it is "spraying" light on, the sensor reads a percentage (from 0-100) of the light being reflected back to it and sends this information to the RCX (the LEGO Mindstroms controller brick).

Darker objects reflect less light; lighter objects reflect more light. The light sensor is a good example of an analog sensor. An analog sensor is one where the value of the output is equal to the value of the input; in our case, the more light, the higher the number and the less light, the smaller the number.





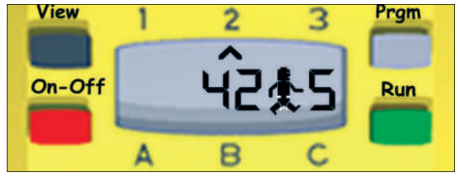
Seeing What the Sensor Sees

Let's do a little experiment. Attach the light sensor to sensor port 2 and download this simple program to the RCX. In order for the RCX to recognize the light sensor, it has to be running a program with a light sensor in it. Make sure that you tell the RCX which port (1, 2, or 3) the sensor is on.

Once your program is downloaded to the RCX, press the green RUN button and

notice that the LED on your light sensor turns on. Press the black VIEW key until the black arrow is underneath the number “2” on the RCX. The display should change to show you what the light sensor on port 2 is seeing.

The two digits to the left of the “running man” will show a lower number (less light reflected back) when the sensor is over a dark surface and a higher number (more light reflected back) when it is over a lighter surface.



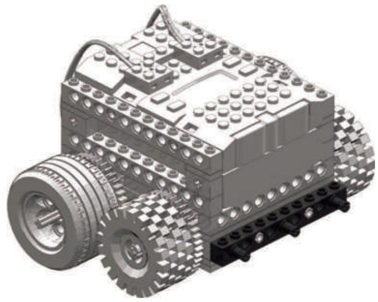
We write programs with the light sensor by telling the RCX to do something until it sees a value of a certain color. Take readings from different objects around you to see which colors represent what values.

Building the Light Sensor Attachment:

STEP 1:

Parts:

STEP 2:



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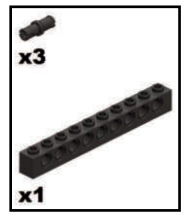
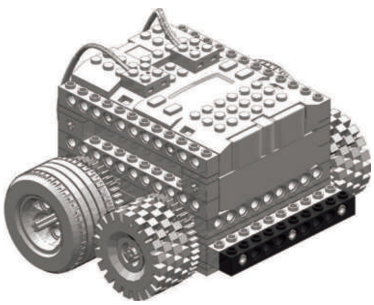


STEP 3:



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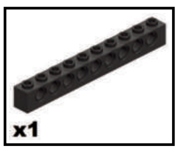
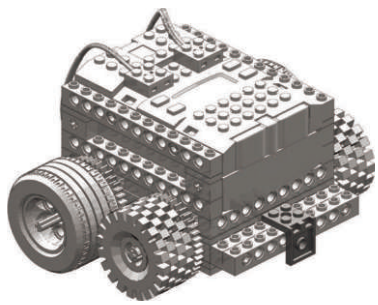


STEP 4:



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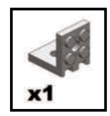
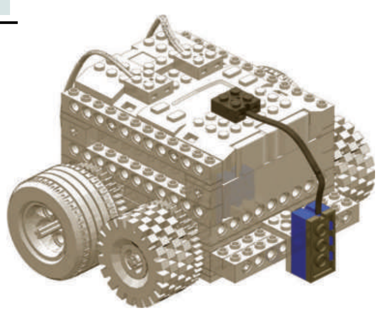


STEP 5:



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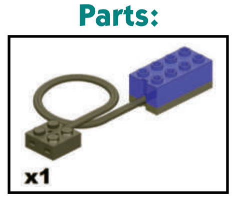


Robot! I Command You! Follow That Line ...

Line following is a popular event at robotic competitions and a fundamental exercise that every roboticist needs to know. Let's write a simple program that uses the light sensor to make Eddie follow a line.

To start, make an oval using black electrical tape on an even, white surface — like poster board or butcher paper. Use the VIEW button to get the values of the black and white areas.

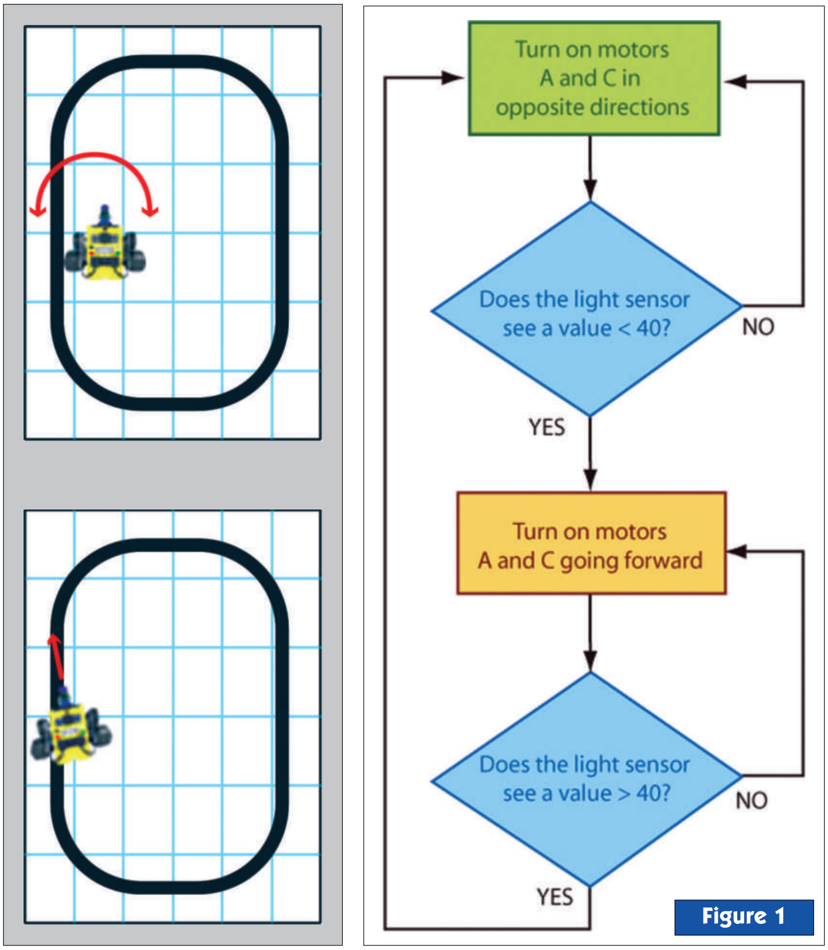


Figure 1

Our robot has one light sensor, so it is helpful to think like a Cyclops to imagine what a one-eyed robot would have to do to follow a line.

Let's place Eddie near one of the line edges. Ask yourself these questions:

1. Which way should the robot move to find the line?

2. How long does it need to move?

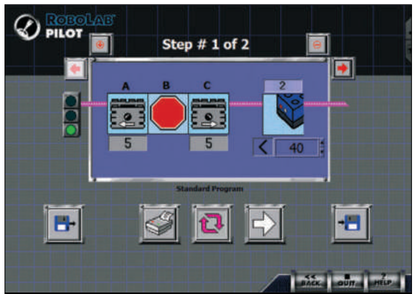
From this position, the quickest way to the line is to turn. Does it matter which way? Nope. Just pick one and stick with it. Once the line is found, the robot needs to stop turning and start following the line by going straight.

These steps make sense and look like they might work, but what happens when we come to a curve? We need to correct our course and turn back toward the line. If we add a third step to turn back toward the line, it makes it difficult to repeat our program. Since we already have a turn in our program, let's try to use it again by selecting the "run continuously" option in Robolab.

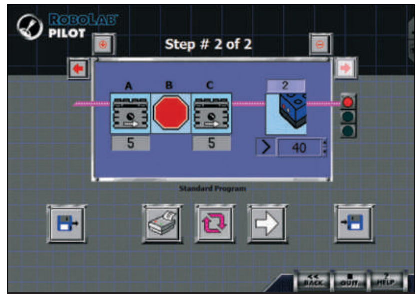
If you go off the line again, all you have to do is start turning again. Your program has two steps:

1. Turn until you see black.

2. Go straight until you see white.
Repeat Forever
or
if the value of light sensor 2 is greater than 40 — turn
if the value of light sensor 2 is less than 40 — go forward
Repeat Forever



Step 1: Turn until you see black (a value less than 40).



Step 2: Go forward until you see white (a value greater than 40).

Figure 1 shows what the flow chart would look like. I used a value of 40. You should use a number somewhere between the values of black and white.

So, if black is equal to a value of 30 and white is a value of 50, 40 might be a good value to start experimenting with.

Try programming your robot by yourself before looking at the following program steps (Steps 1 and 2 on the following page).

That's it! Your robot should be scooting around the line. This is a pretty simple line follower program (actually an edge follower) and it probably won't take you too long before you notice some of its limitations, but think of all the cool things you can do with a single light sensor.

You could hold drag races where you race your opponent to a black line at the end of a long course. Hold a sumo match where your robot tries to push an object — or even another robot — out of the ring while trying to stay in the ring itself.

What can you do with a single line sensor? Send me your ideas at **james@megagiant.com** and I'll share them on my website and, if you want to find out what goes on inside a LEGO light sensor, visit **www.plazaearth.com/usr/gasperi/light.htm**

In the next installment, we will improve on our line follower by adding an additional light sensor to the front that will make Eddie more accurate and allow it to navigate even the most complex lines.

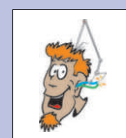
As always, the above program is available on the *SERVO Magazine* website (**www.servomagazine.com**) and my website **www.theroboticslab.com** SV

Definition

Analog Sensor: a sensor where the output value varies in direct relation to the level of input.

Author Bio

James Isom is a part-time robotics teacher and general all-around geek. He has taught robotics to children and teachers in the US and abroad. His website with other additional goodies (including the MLCAD file of this robot) can be found at **www.theroboticslab.com** He can be reached at james@megagiant.com



New Products

ACCESSORIES

Li-Ion Battery Packs Feature On-Board Charging Circuits

Custom-manufactured lithium ion battery packs that provide high energy density and can include charging circuits and other electronics are being introduced by Aved Electronics, Inc., of Lowell, MA.

Aved Custom Li-Ion Battery Packs can incorporate onboard circuitry to gauge charge, temperature, and remaining run time, where applicable. Providing five times the energy density of comparably sized NiCad packs, these battery packs can be made in cylindrical, prismatic, and coin cell configurations with capacities ranging from 500 mA to 20 amps.

Shaped to fit cavity design requirements, Aved Custom Li-Ion Battery Packs combine high power and high energy density in a lightweight package that can be supplied with flying leads, pressure contacts, and solder-, surface mount-, and quick-connect connectors. Suitable for use in a variety of portable devices, they operate from -20°C to +70°C.

Aved Custom Li-Ion Battery Packs are priced according to configuration and quantity, with 5,000 minimum units per year typical. Literature and price quotations are available upon request.

For further information, please contact:

Aved Electronics

59 Technology Dr.
Lowell, MA 01851
Tel: **800•441•2833** Fax: **978•453•6470**
Email: **info@aved.com**
Website: **www.aved.com**

Circle #69 on the Reader Service Card.

MECHANICS

CQM Compact Cylinder

SMC Corporation, the world's largest manufacturer of pneumatic automation products, has announced the introduction of the Series CQM Compact Cylinder with Guides. SMC's recently developed CQM Cylinder is now available from SMC's Los Angeles, CA production facility. This factory can produce all bore/stroke combinations in both metric and inch versions.

The CQM cylinder incorporates slide bearings into SMC's global standard CQS and CQ2 compact pneumatic cylinders, creating an extremely compact, guided cylinder. The CQM cylinder fills a product gap between low side load non-rotating cylinders and higher load guide rod actuators, such as SMC's MGP and MGQ guided cylinders. The CQM is designed to meet or exceed 10 million cycles, ensuring long life.

The CQM cylinder offers excellent non-rotating accuracy: ±0.2° for bore sizes 12 and 16 mm and ±0.1° for bores 20 to 50 mm. The cylinder is designed to allow for easy mounting and adjustment of SMC's extensive selection of position sensing switches. With two to four times the lateral load resistance of a standard compact cylinder, the CQM cylinder is ideal where moderate side loading may be an issue.

The CQM cylinder has a maximum operating pressure of 1.0 MPa and is available in seven bore sizes, ranging from 12 to 50 mm with Imperial or metric mounting threads/ports. Bore sizes of 12-40 mm have a piston speed range of 50-500 mm/s; the 50 mm bore size has a piston speed range of 50-300 mm/s. The ambient/fluid temperature ranges for the CQM are -10 to 70°C without the auto switch and -10-60°C with switch. All varieties of inch mounting and tool plate threads are available.

For further information, please contact:

SMC Corporation of America

141 Myford Rd.
Tustin, CA 92780
Tel: **714•669•0941**
Email: **joanna@phaze-9.com**
Website: **www.smcusa.com**

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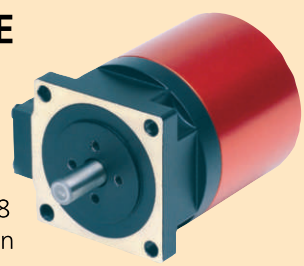
MOTORS

TG2300-120-81920E BLDC Motor



ThinGap has introduced the TG2300-120-81920E BLDC Motor. In its NEMA 23 frame size, it can be run from 12 to 48 VDC and will develop 574 oz-in

of peak torque pulling 70 amps at the highest voltage. It presents zero cogging or hysteresis torque and sports a very high power density (7.5 W/oz), as well as a high efficiency. Due to its high torque constant (Kt = 8.2 oz-in/amp), the need for gearing is greatly reduced. Control engineers will appreciate its linear response, making it ideal for use under closed loop control.

For further information, please contact:

ThinGap Motor Technologies Tel: **805•477•9741** Fax: **805•477•7535**
Email: **info@thingap.com**
Website: **www.ThinGap.com**

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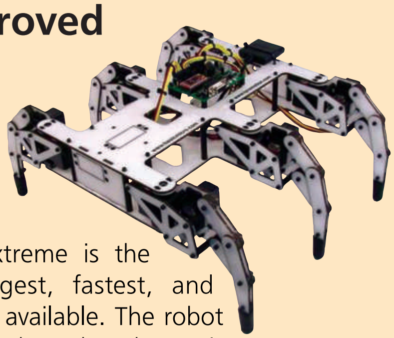
ROBOT KITS

New and Improved Hexapod!



Lynxmotion has pulled out all the stops on 12 servo hexapod walker technology.

The Hexapod 2 Extreme is the result. This is the largest, fastest, and lightest 12 servo walker available. The robot can walk forward or backward and turn in place — left or right — with variable speed. This means it can go from a crawl to a full speed run and everywhere in between. This robot can easily do gradual turns. It uses Hitec HS-422 servos for plenty of speed and power. It's very fast, agile, and responsive.

It can be assembled in about three hours using basic hand tools, such as hex drivers and pliers. The legs are mechanically adjustable to make software calibration a thing of the past. The advanced leg design features low power consumption when the legs are standing. The Bot Board and Atom Pro make control of a complex walking robot effortless. Lynxmotion has an R/C version based on the MadCatz wireless PS2 game controller for demonstrations.

Simply plug the servos and controller into the board, download the program, apply power, and the robot walks under remote control. Autonomous versions for the IRPD, Sharp GP2D12, and ultrasonic object sensors are coming soon.

Because Lynxmotion has taken care of the walking process for you, it is easy to write your own behavior program. Controlling the robot's speed and direction only requires changing a couple variables in your program. The walking routines are precise, which means changing from one direction to another is a smooth transition.

This robot sells for $468.68, complete. This includes the robot, Bot Board, Basic Atom Pro, PS2 cable, and 7.2 VDC 1,600 mAh NiMH battery pack and charger. The specs are as follows:

Height = 5.5"
Width = 16.0" (leg to leg)
Length = 13.5"
Ground clearance = 3.5"
Weight = 3 lbs, 4 oz (complete)

For further information, please contact:

Lynxmotion Incorporated Tel: **866•512•1024** or **309•382•1816**
Fax: **309•382•1254**
Website: **www.lynxmotion.com**

Circle #107 on the Reader Service Card.

TOOLS & TEST EQUIPMENT

Development System Speeds USB Integration

Linx Technologies has released a Master Development System for the exciting new QS Series USB module. The cost-effective QS module provides a complete solution for bi-directional data transfer between USB and CMOS/TTL level sources. The module can be directly connected to any serial device, including microprocessors, RS232/RS485 level converters, or Linx wireless RF modules.

The development system is designed to assist in the rapid evaluation and integration of the QS module. It contains a fully assembled board and comprehensive software that demonstrates the interface of a microcontroller or RS-232 device with a PC via the QS USB module. A prototyping area with a signal breakout header and complete documentation speeds the addition of USB to virtually any device.

The $129.00 development system is immediately available.

For further information, please contact:

Linx Technologies 575 SE Ashley Pl.
Grants Pass, OR 97526
Website: **www.linxtechnologies.com**
or **www.instantusb.com**

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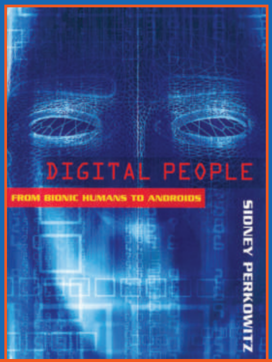
DIGITAL PEOPLE



FROM TALOS TO QRIO

by Edward Driscoll, Jr.

When Dr. Sydney Perkowitz went looking for a subject for his latest book, *Digital People: From Bionic Humans to Androids*, his topic began to seem obvious. "Every time I picked up a newspaper or magazine," Perkowitz says, "there was an item about robots, androids, or bionic people. This widespread appearance of robots had been building up — especially over the last few years — and went all the way from media figures, like *Star Trek*'s Commander Data, to robotic pets, like Sony's AIBO, to very serious applications, like robotic weapons and advanced bionic implants.

Is Commander Data the future of robotic development? Photo courtesy of Paramount Home Entertainment.

Artificial beings, it seemed, had become a cultural and technological reality and I wanted to tell that story more fully than anyone else had."

Perkowitz is the Charles Howard Candler Professor of Physics at Emory University (**www.physics.emory.edu/faculty/perkowitz/**). *Digital People* is a follow-up to his popular, if offbeat, 2000 title, *Universal Foam.* About *Foam*, *Publishers Weekly* wrote, "Deftly blending theoretical discussion with real world examples, Perkowitz introduces readers to foams, both liquid (shaving cream, whitecaps, beer) and solid (cork, pumice, and a nearly insubstantial high-tech material called aerogel).

The book is a something-for-everyone tour, led by a guide who sees voids and bubbles wherever he looks."

As Yoda might say, foam is the Force that binds the universe together; yet, after completing his book on the subject, Perkowitz began to see another common element to the universe — or at least planet Earth — that he wanted to explore: droids. Err, robots, that is.

Perkowitz describes *Digital People* (Joseph Henry Press, 2004; **www.jhpress.org/jhppubs.html**) as a look into, "the technology and the meaning of every kind of artificial and semi-artificial being.

It reviews the history and current status of the technology, considers what artificial beings have meant to the human imagination through literature and the media, and points out future possibilities — positive and negative — for robotics."

Talos: The First Robot

As Perkowitz highlights, mankind has had a long history of, first, dreaming about and, later, building surrogates of ourselves. "If you extend your thinking about mechanical men and artificial beings to include dolls, sacred idols, puppets, and so on, you see that the impulse to build imitations of humans or superior versions of humanity is extremely ancient.

"It would take a roomful of anthropologists, psychologists, theologians, philosophers, and more to understand all the reasons that we humans are fascinated by artificial versions of ourselves, but I think some of the factors are a desire to better understand ourselves, a desire to transcend our physical and mental limitations, and, finally, our fear of death."

In *Digital People*, Perkowitz writes about the mythological Talos, "a bronze being built by Hephaestus, the Greek god who later became the Roman god, Vulcan — the god of the forge who made all sorts of marvelous implements and who we might now call the god of technology. Talos guarded the island of Crete by patrolling its shore, detecting hostile ships and throwing rocks at them."

Because he was, "metallic, mobile, larger than life, and had considerable intelligence, it's fair to call Talos the first robot," Perkowitz explains.

Talos first appeared in mythology hundreds of years before Christ. Going forward a couple of millennia,

there were numerous additional examples of the dolls, sacred idols, and puppets that Perkowitz spoke of earlier.

In the 18th century, however, something quantitatively different first appeared. "Although they are technically automata rather than robots (meaning that they can follow only one behavioral program that never changes)," Perkowitz says, "I was incredibly impressed by the clockwork mechanical beings made by 18th century artisans. These looked and acted like people — writing letters, drawing pictures, and playing musical instruments (in one case, playing a flute by actually expelling air into it so that the automaton seemed to be breathing)." For more on these amazing automata, see "Geerhead" in the May 2004 issue of *SERVO*.

The 20th Century: The Dawn of the Robot Nation

Of course, it was in the 20th century when robots really began to seem commonplace, particularly in the movies, as I detailed in the November 2003 issue of *SERVO*. What caused this past century's particular fascination with robotics? Perkowitz says, "There were earlier stories about various kinds of artificial beings — from the Golem to Frankenstein's monster — but, in the 1920s, the stage play *R.U.R. (Rossum's Universal Robots)* introduced the actual word 'robot' and the film *Metropolis* introduced a definitive kind of machine-like robotic look."

Then, technology began to catch up, Perkowitz says. "The continuing interaction between imaginary and real robots has steadily enhanced people's fascination with the whole topic."

Not all robots in the 20th century were shaped like humans. Perkowitz says that one robot that seemed, "far beyond its time was the 8-foot-tall Elektro and his dog Sparko, built for the 1939 New York World's Fair. Though the electronic technology of 1939 was primitive by our standards 65 years later, Elektro could talk, walk, dance, and even smoke a cigarette. He was a hit of the Fair and helped to convey the idea that technology is not necessarily something to fear." (Again, *SERVO* chronicled this amazing creation in Tom Carroll's article in the April 2004 issue.)

Later, robots moved beyond both science fiction and demonstrations like Elektro into more practical reams: In 1961, Dr. Joseph F. Engelberger built the first robots for General Motors' assembly lines (See Ed Driscoll's article in the March 2004 issue of *SERVO*.)

2001: A Cyborg Odyssey

Over 40 years have passed since the debut of Engleberger's assembly line robots. The first decade of the 21st century isn't even half over and robots are rapidly becoming almost as ubiquitous as the droids of the *Star Wars* films. There are over 200,000 robots serving alongside humans on automobile assembly lines. An increasing number of Engleberger's hospital robots are rolling down infirmary corridors across America.

On a more domestic note, Roombas patrol many a living room and AIBOs scamper across thousands of dens while their human masters watch *Battlebots*, *Robot Rivals*, or one of the myriad of robot-studded sci-fi movies that inspired these TV shows.

Of course, today's robots aren't quite as smart as *Star Wars*' C3P0 or R2-D2 nor are they as lifelike as *Star Trek*'s Mr. Data. Both feats may be possible, though, sooner than we think. Perkowitz believes that, "the most interesting direction is the development of robots that are meant to interact with people in meaningful ways."

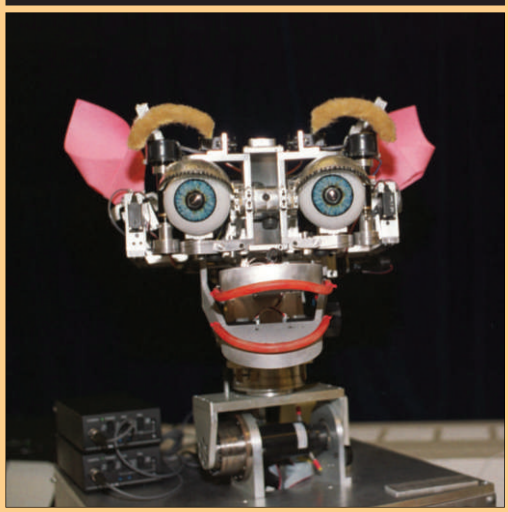
He sites Kismet, designed by Cynthia Breazeal of MIT's Artificial Intelligence Laboratory (**www.ai.mit.edu/people/cynthia/cynthia.html**). Kismet is essentially a robotic face whose oversize eyes, eyebrows, and mouth register surprisingly life-like emotions as it interacts with humans. Perkowitz describes Kismet as a breakthrough because, "it emphasized social interaction and the possibility of a human teaching a robot, rather than sheer physical capability (essential though that is)."

Perkowitz is also rather fond of Sony's QRIO robot (**www.sony.net/SonyInfo/QRIO/**). QRIO is a surprisingly adorable silver mechanical man, roughly the same size as Sony's AIBO robotic dogs. Unlike AIBO, QRIO (which stands for "quest for curiosity") walks upright and can right himself when he falls over.

He also dances (seemingly everything from kabuki to disco), bobs, weaves, bows, and all in startlingly life-like fashion. He can also talk by using software that converts text to speech. Perkowitz says that QRIO displays, "a good deal of social intelligence." He adds, "In general, I rate QRIO as today's most exciting robot. It demonstrates just how far we have come in implementing all the artificial physical and mental capabilities that will lead to truly intelligent robots."

Will QRIO's future big brothers come to resemble the replicants of the 1982 film *Blade Runner*, who were a combination of robotic mechanisms and human biology? "That first robot we talked about already foreshadowed the mixture of mechanical and organic elements.

Kismet — the robot that displays emotions. Photo courtesy of Donna Coveney of MIT.



Is a Backlash Against Robots on the Horizon?

As technology progresses and robots become even more omnipresent — and more lifelike, as well — does Dr. Perkowitz think there will be a backlash against them? Is something along the same lines as the fears that many have today about cloning in the future of robotics?

He believes it could happen. "Because — as robots become smarter — they become less predictable and that can naturally raise fears of runaway technology. People are beginning to worry about this issue and are considering the right kinds of constraints to help robotics function as a helpful, rather than harmful, technology. (For instance, this topic was raised at an international conference on roboethics held in Sanremo, Italy in early 2004.)"

Perkowitz also thinks, "there could be a backlash against turning over jobs from humans to robots, which becomes more likely as robot labor becomes cheaper than human labor.

"There's another kind of backlash that's possible when you consider human/machine hybrids, such as bionic people (for instance, those with cochlear implants or with electronic implants that help the heart function correctly — one of which I have myself). Hybrid beings could raise some of the same issues as cloning does; for instance, if hybrid technology reaches the point where it can actually enhance a person, who should be eligible for these enormous benefits? And is a largely artificial person still a person?"

Though Talos' construction was of bronze, it had a vein through which flowed the blood of the gods, called ichor. I think such machine/organic combinations are an extremely important direction for the technology to follow. In some cases, this will be because human engineering still can't match what millennia of natural evolution have accomplished, so robots may include organic or natural elements that outdo anything artificial. Further, the sheer medical and societal value of developing machine/organic hybrids dictates that this will be a significant technology."

The gains made in the last 100 years by robotic technology are nothing short of astonishing. "The continuing interaction between imaginary and real robots has steadily enhanced people's fascination with the whole topic," Perkowitz says and *Digital People* will only increase it. Talos, no doubt, would be proud. **SV**

From Mars to Your Window Sill

by Roger G. Gilbertson

Building a Model MAE with Muscle Wires®

Getting to Mars

The first part of this article appeared in the April 2004 issue of *SERVO* and tells the story of how a short length of a unique shape memory alloy wire made its way from a drawer in the closet of my two bedroom apartment to the surface of another world as part of an instrument aboard the Mars Pathfinder Sojourner Rover, which touched down on Mars on July 4, 1997.

Since dust build-up reduces the effectiveness of the solar panels, high dust levels could bring an early end to a solar-powered robot's mission on the surface of Mars. To examine the severity of this issue, NASA sent an experiment to Mars. Mounted on a corner of the robot's flat solar panels, the MAE (Materials Adherence Experiment) measured dust accumulation during the 1997 Mars mission.

Figure 1. Materials Adherence Experiment aboard the Mars Pathfinder Sojourner Rover.

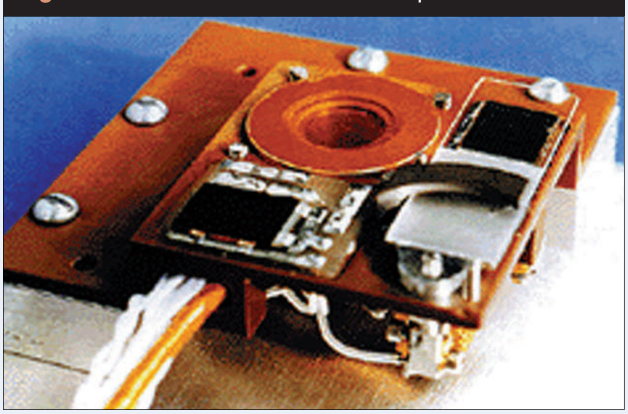
Dr. Geoffrey Landis from NASA's Lewis (now Glenn) Research Center developed the MAE. With fellow researcher Phillip Jenkins, he crafted the Mars-worthy device that consisted of a thin, transparent plate positioned above a small solar cell, and using a 3 cm (1.2 inch) length of Flexinol 150 LT Muscle Wire to move the clear plate.

When powered, the Muscle Wire rotated the plate aside, permitting the calibration of the light sensing solar cell by direct exposure to the sunlight. When powered off, the Muscle Wire relaxed, permitting the dusty slide to return to its starting position over the sensor. Subtracting measurements from the two positions gave a measure of how much dust had accumulated.

Designed and built by a team at NASA's Research Center, the MAE was inspired by a Muscle Wire demonstration device shown by the author at a conference entitled "Practical Robotic Interstellar Flight: Are We Ready?" sponsored by the Planetary Society in the fall of 1994.

The results of the MAE's measurements showed that Martian dust collected on the Sojourner's top surface and reduced the energy that reached the solar panels by 0.30 percent per "sol" (Martian day). In addition, the researchers observed that the rate of dust build-up appeared the same, whether the Rover drove about or remained in place, indicating that the dust was settling out of the atmosphere, rather than being created by the robot's activities. These results affected decisions regarding the design of the Mars Exploration Rovers — Spirit and Opportunity — which started to explore Mars in January of 2004. The same type of dust build-up has been photographically observed on these Rovers, but they carry no instrument like the MAE. For more on the MAE instrument and its results see: **http://powerweb.grc.nasa.gov/pvsee/experiments/MAE.html**

Figure 2. The Materials Adherence Experiment or MAE.



An Earth-Based Project

The previous article presented instructions for building a simple lever arm device out of cardboard that is operated by a length of Flexinol 150 Muscle Wire. This article describes a microcontroller circuit that operates the Muscle Wire lever arm, uses a small cadmium sulfide (CdS) photocell to measure dust build-up, and displays the data on an LCD module.

Built around the popular BASIC Stamp 1 from Parallax, this project provides a great venture for intermediate level experimenters. With it, you can measure the build-up of dust on your desktop in a manner like the MAE did. You will also gain experience with interfacing analog, digital, and serial devices to a Stamp and in driving Muscle Wires from a microprocessor.

If you have already built the lever arm project as described in the previous article, you can use it with this circuit by simply adding a short segment of clear plastic to the end.

Alternately, you may wish to build a separate lever arm, using more durable materials, such as acrylic plastic, screws, standoffs, etc. (See Figure 4.) This will give you a longer-lasting device that should operate for many sols without interruption.

Circuit Parts

J1 can be wires soldered to the circuit and connected to a power supply. Note that a 9 V battery does not generally have enough power to operate the Muscle Wire effectively for very many cycles.

J2 and J3 represent optional headers and ribbon cable or hook-up wires that permit the Lever Arm/Sensor module and LCD Serial Display to be mounted separately from the Stamp 1 Carrier Board.

Also needed: a DC power source (9 V DC, 500 mA or greater), BASIC Stamp 1 software, and programming cable (available from **Parallax.com**), assorted hookup wire, connectors, plus the usual selection of hand tools, soldering iron, moist sponge, solder, etc., for assembling electronics (see sidebar for details).

Assembly Notes

The Stamp 1 Carrier Board makes for easy assembly of this circuit, as it contains a socket for the Stamp 1 and connection points for power and all Stamp 1 functions. It also includes a header for the programming cable, a reset switch, and an array of plated through holes perfect for "scratch building" this circuit.

However, you may construct the circuit on perfboard, if you prefer. These instructions assume you are a user who has some experience in building circuits "from scratch." If any steps seem unclear, please consult with a hobbyist or experimenter who has done this kind of thing before.

Connections for the Stamp 1 programming port and reset switch connections are not shown, but they are provided on the Stamp 1 Carrier Board.

Give some thought to the placement of the parts on the board so as to make for easy hook-up. Make a photocopy of the schematic in Figure 3 and follow it closely, using a colored highlighter to cross out each component and each connection as you install it. Be sure to connect all power and ground links, as well.

When soldering, remember that neatness counts. The finished board should represent a work of art (at least to you!).

Mount VR1 — the CdS photocell — at the end of wires that are about 15 cm (6 inches) long, so as to easily place it under the transparent end of the lever arm. To connect from the circuit to AA1 — the Muscle Wire actuator — use very thin wires (like wire wrap wire) so they will not limit the motion of the lever. Attach the thin wires to the Muscle Wire by catching them both under washers and screw heads.

When completed, check over the entire circuit — one component at a time. Use a second color of highlighter on the schematic and mark each component off.

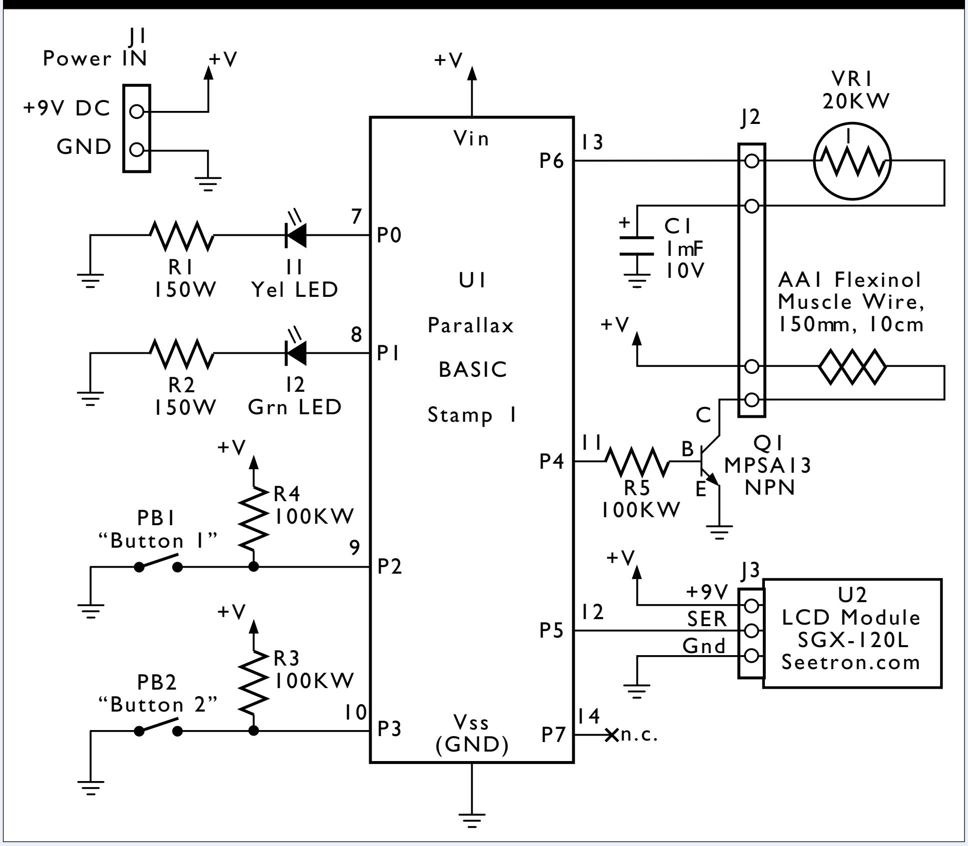
At this point, you may attach the lever arm built of cardboard. However, for a more long-lasting demonstration device, use Figure 4 as a guide for constructing a new lever arm using a plastic sheet. All the parts can fit onto a rectangle of plastic measuring 110 x 180 mm (4.375 x 7 inches), as shown in Figure 4.

Use aluminum standoffs, washers, and screws to mount the LCD display and Stamp 1 Carrier board to the base. Also, use aluminum standoffs to mount the Lever Arm and the fixed

Circuit Parts

	Quan	Location	Description
1.	2	R1, 2	Resistor, 150‡, 1/4 W
2.	3	R3-5	Resistor, 100K‡, 1/4 W
3.	1	VR1	CdS Photoresistor, 1-20K‡
4.	1	C1	Capacitor, 1 µF 10 V min
5.	1	I1	LED, Yellow, T1
6.	1	I2	LED, Green, T1
7.	1	Q1	Transistor, MPSA13, NPN
8.	2	PB1, 2	Switch, momentary, pushbutton
9.	1	AA1	Flexinol Muscle Wire, 150 µm, 10 cm long (**RobotStore.com**)
10.	1	U1	BASIC Stamp 1 (from **Parallax.com**)
11.	1	U2	Serial LCD Module (like SGX-120L from **Seetron.com**)
12.	1	—	BASIC Stamp 1 Carrier Board (Parallax #27110)

Figure 3. Schematic for Sensor, Processor, and Actuator circuits.



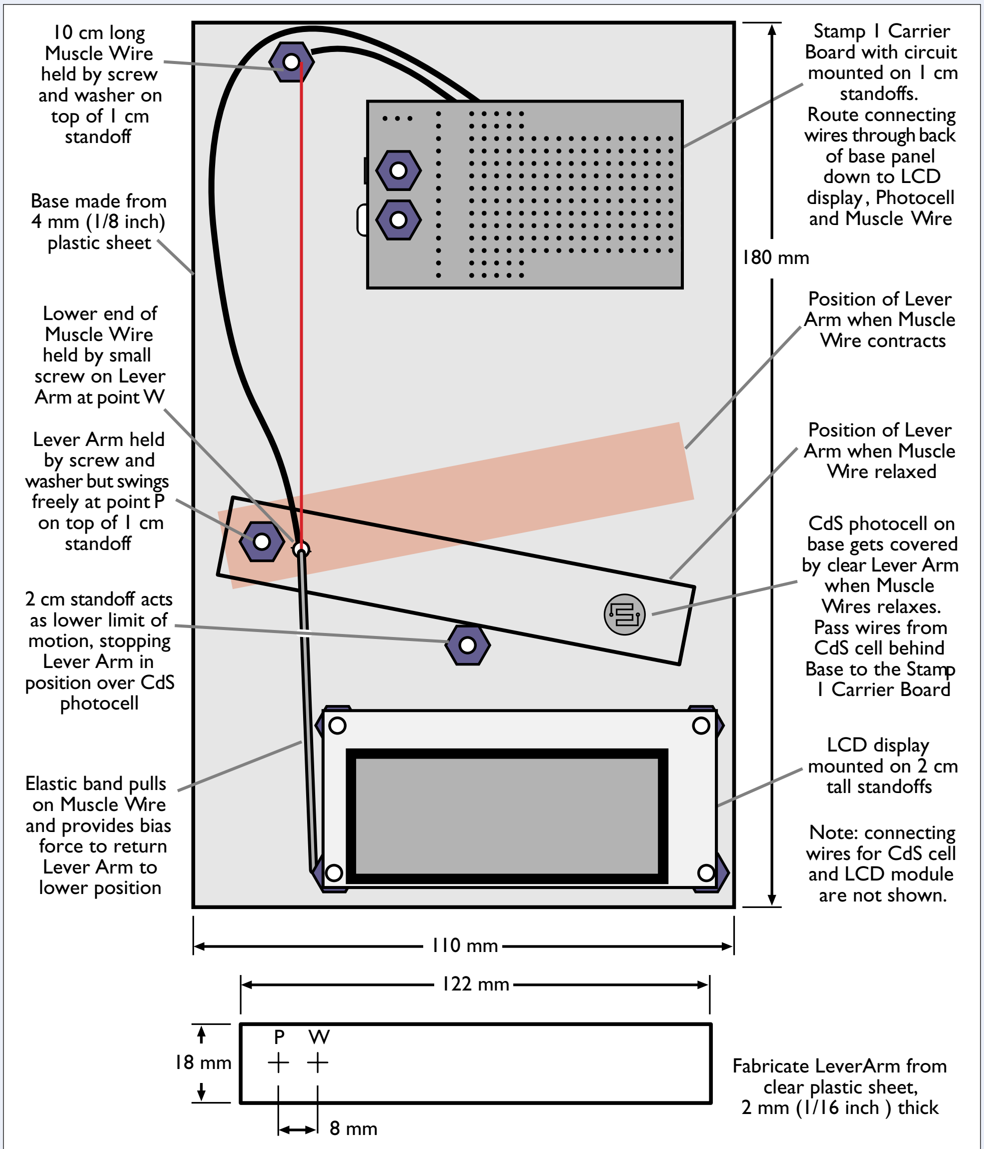


Figure 4. General Assembly of Lever Arm, Sensor, LCD Display, and Stamp 1 Carrier Board.

(upper) end of the Muscle Wire. A thin band of elastic (from a sewing store) provides the return force needed by the Muscle Wire.

Programming

When the circuit has been fully built and checked over, connect the programming cable, boot up the Stamp 1 software on your PC, apply power to the circuit, and then download the program listed in Figure 5.

You may download this file from our website at **www.RobotStore.com/support** under the link "Mars MAE Demo Stamp 1 code."

As soon as the download is finished, the device should start operating; it will begin lifting the lever arm, holding still for a moment, and then relaxing. After a few cycles, turn off the power and adjust the position of the Muscle Wire so that there is no slack when it is relaxed.

If the circuit seems to have too much or too little power to activate the Muscle Wire, try changing the power and time values in the program (as in the command pwm 4, 150, 200) and download it again. Even with a very clean plate, the CdS photocell has just enough sensitivity to recognize the difference between the Muscle Wire's contracted and relaxed states.

Note that Button 2 is not used in the program, but you can write your own code that uses it to start a special calibration routine, reset the counters, change the display format, or perform other operations.

Many more variations can be created using the methods shown here, so start experimenting. You can easily interface it to a PC (or, if you

About the Author

*In college, Roger G. Gilbertson studied engineering, robotics, and the walking patterns of living creatures. In 1987, he co-founded Mondo-tronics, Inc., to explore the commercial applications of Shape Memory Alloy wires and, in 1995, launched **RobotStore.com**, the Internet's first commercial robotics site. Mondo-tronics' Robot Store continues to lead the field in presenting the best and most innovative new robot products for students, educators, hobbyists, and experimenters. Roger lives and works in Marin County, CA, where, unfortunately, most house pets exhibit greater intelligence than most robots.*

wish, omit the LCD module and just use the PC) to log the data and monitor dust build-up over time.

For more on the history, applications, and projects using Muscle Wires, refer to the *Muscle Wires Project Book*, Third Edition, ISBN 1879896133, available from RobotStore.com and wherever fine project books are sold.

Summary

Inspired by a truly "out of this world" device, this project gives an introduction to using a microcontroller for driving Muscle Wires, reading analog devices, and sending serial data to an LCD display.

So go forth! Explore the Universe and build cool stuff. Perhaps you will build a device that will someday find its way to another world. It has happened before.

And, of course ... Build more robots! **SV**

Figure 6. The LCD Display shows results of the dust build-up.

Figure 5. MarsMAE1.BAS Program Listing.

```
'MarsMAE1.BAS
'Mars MAE BASIC Stamp program — RG 9911.03-0403.23
'for SERVO Magazine article

'Stamp 1 program for reading a CdS photosensor, driving
'a Muscle Wire lever arm, calculating results and
sending
'them to an LCD display at 2,400 baud with backlight
control

'set Input/Output directions
output 0          'Yel LED output
output 1          'Grn LED output
input 2           'Button 1 input
input 3           'Button 2 input
output 4          'MW output
output 5          'LCD display
input 6           'CdS Sensor input

w0 = 255
w1 = 255
w2 = 255
symbol i = w4   'counter i

'setup LCD display
pause 1000
serout 5, N2400, (12)   'clear LCD screen
serout 5,N2400,("  ",2," Mars Dust Level ",3,13)
'2=inverse, 3=normal
GOTO display             'put up rest of text

'Program loop
loop1:
IF pin2 = 1 THEN skip1   'if button 1 not pressed then
skip gosub
GOSUB LCDonoff           'if button 1 pressed, go
toggle LCD & LED

skip1:
pin0 = 1                 'Yellow LED ON
pwm 4, 150, 200          'activate Muscle Wire (pin,
power, time ms)
pwm 4, 30, 100           'hold open (pin, power, time
ms)
pin0 = 0                 'Yellow LED OFF

'check BRIGHT light level
pot 6, 75, w0            'read port 6, store in word 0
w2 = w1 - w0             'update the difference
pin4 = 0                 'turn Muscle Wire off

FOR i = 1 TO 3500        'wait for Muscle Wire to relax
IF pin2 = 1 THEN skip2  'if button 1 not pressed then
skip gosub
GOSUB LCDonoff           'if button 1 pressed, go
toggle LCD & LED

skip2:
NEXT i
                         'check DARK light level again
pot 6, 75, w1            'read port 6, store in word 1
w2 = w1 - w0             'and update the difference

display:
serout 5,N2400,(16,#21,"    Bright: ",#w0,"   ",13)
'13 is CR
serout 5,N2400,("      Dark: ",#w1,"   ",13)
'13 is CR
serout 5,N2400,("Difference: ",#w2,"   ",13)
'13 is CR

GOTO loop1


'***** SUBROUTINES
LCDonoff:
IF pin1 = 1 THEN lcdoff 'if green LED ON then go turn
OFF
serout 5, N2400, (14)   'turn LCD backlight ON
pin1 = 1                 'turn green LED ON
goto wait

lcdoff:
serout 5, N2400, (15)   'turn LCD backlight OFF
pin1 = 0                 'turn green LED OFF

wait:
if pin2 = 0 then wait   'wait for button up
pause 10
RETURN
```

GEERHEAD

by David Geer
geercom@alltel.net

Exoskeleton Realized! PLUS Cyborg Technology News!

The Berkeley Lower Extremity Exoskeleton (BLEEX) helps lighten the load for the human user. Photo courtesy of Homayoon Kazerooni, UC Berkeley.

Now, here's a story with legs on it!

Body by BLEEX [The Berkeley Lower Extremity Exoskeleton]!

Phase one of the first functional exoskeletal leg and backpack apparatus is complete. The next phase of development will approach size reduction, increased transparency to the user, and increased strength, responsiveness, and duration. The estimated arrival time for these objectives is the Summer of 2005. At that point, the exoskeleton should be field ready.

Challenges

There are many challenges in accomplishing these goals in such short order.

Finding the right materials to meet the demands and designing for transparency while achieving marked increases in its capabilities are only a few of them.

Each of the exo's component parts is made of the best-suited material for the task. Bearing houses are made of stainless steel. The computer housing is carbon fiber. Stress, location, temperature, and function help determine the material composition that is used for these and other components. Other materials in the current exo include titanium, aluminum, polycarb, and ABS. Even better materials must be found to meet phase two objectives.

Where will they find them? What will they use? Any ideas?

Sketching It Out

BLEEX consists of two legs, a gas engine, a frame like a backpack where loads can be carried, and a computer. BLEEX employs mechanical metal leg braces to carry the brunt of any load. These are connected rigidly and securely to the feet.

The braces themselves, however, are flexible, so that they won't transfer force or friction to the user. The wearer requires no training to use the machine.

The machine also consists of over 40 sensors and hydraulic actuators, which together form a BodyLAN (see

Lessons from BLEEX sidebar). Like a central nervous system, sensors in the shoes and throughout the robot give continual data to the computer brain. The brain then adjusts the load based on the human activity so that the wearer doesn't feel the load (at least not more than five pounds of it).

How Do You Put It On?

The wearer puts on specially retrofitted army boots. These are attached to the BLEEX exoskeleton — to the metal leg frames — which are on the outside of each leg.

Next, the pilot puts on the vest, which includes the backpack frame and the engine.

Software That's Born Free

Improvements to the control algorithm are required so that it will be more robust in order for the exoskeleton to quickly and seamlessly adapt and adjust to load variation, load shifting, and human movement.

Thanks to this algorithm, the exoskeleton responds to the pilot's movements without requiring forceful interaction. The controller takes measurements from the exoskeleton and computes how to move so that there is little force on the pilot (forceful contact between the pilot and the machine).

Exo-Fashion

The design requires adapting the machine very carefully to the variety of movements and conditions of the human gait — how we walk, run, and perform other movements. The exoskeleton had to be flexible to suit natural human movement. Human gait information was also considered in designing the exoskeleton's

Photo courtesy of Homayoon Kazerooni, UC Berkeley.

Berkeley Cyborg Technology News

Cyborgs we promised — Cyborgs you get.

Kevin Healy is Professor of Bioengineering at UC Berkeley. Included in his work is cyborg technologies; this branch of technologies aids human or other mammal physiological processes using electronic or mechanical devices. Yes, if you know someone with a pacemaker, you know a genuine cyborg.

As we know, many times the human body or host will reject artificial implants — those mechanical or electronic devices — because our biology rejects foreign matter. Healy's research involves the discovery of biomimetic materials that will help join man and machine without failure or rejection.

Biomimetics is the study and use of synthetics to do some of the work of biological molecules. Professor Healy's job is to make those synthetics "Welcome." So far, the professor's work in developing hydrogels for tissue regeneration and synthetic polymers for gene therapy has been making great strides.

Boris Rubinsky — Professor of Mechanical Engineering and Bioengineering at Berkeley — is involved in discovery in bioelectronics. He is making progress in several veins in the bionic research arena.

Rubinsky has a basis for monitoring cryosurgery over the Internet. Cryosurgery uses extreme cold to selectively eliminate abnormal cells. This could help bring cryosurgery to rural areas across the globe.

Another of Rubinsky's discoveries can help tell whether a cell is alive or dead, based on its electrical resistance. This could be used to determine if a minimally invasive surgical procedure has been successful.

For further reading on cool cyborg research, check out these links:

Researchers have created a potentially toxic sensor chip by combining electronics with a living cell: **www.berkeley.edu/news/media/releases/2003/06/09_toxic.shtml**

A bionic chip merges a living cell with electronics (circuitry): **www.berkeley.edu/news/berkeleyan/2000/03/01/bionic.html**

"Master Fabricator" Paul Guinan. Photo courtesy of Paul Guinan.

power distribution sub-systems, actuation, and architecture.

The first stage of the project, in fact, involved researchers gathering and analyzing their own information about how we walk. Words we might not normally use to describe taking a walk in the park are used to define the analysis undertaken — propulsion, torque, shock absorption; all these factored into adapting the exo to you and me.

By also allowing for "worst case scenarios" in movement, the result is an exoskeleton that helps maximally in carrying the payload while constituting a minimal distraction and discomfort itself.

And More Work ...

Other hurdles to overcome for the next version also include run time. The current device can't run more than an hour. The final model needs to run for at least four to five hours — or more. The device also can't attain a full squatting posture; the human pilot can't squat all the way down. The machine needs to be much smaller and more transparent.

The phase one BLEEX exo enables a human being to traverse flat and sloped surfaces. Future endeavors focus on making the robot smaller, the engine more silent — yet mammoth in strength — and the controller more brilliant. The exo must also learn to cooperate with our maneuverability more so that we can run and jump with it.

Finding Its Purpose

BLEEX is intended to reduce stress and discomfort on the wearer, be highly adaptive to human maneuvering, and be technically flexible so the wearers can move in any way they normally would, even though they are carrying heavy supplies.

The target payload for a backpack supported by BLEEX is from 120 to, hopefully, 160 lbs. This is based on the largest backpack payloads of today's soldiers and general backpackers. If the pilot of one of these final BLEEX products is carrying more than the maximum payload, the machine won't fail. Rather, the load will be shared between the exoskeleton and the individual.

This machine will enable the human pilot's endurance to be reserved, extended, and redirected elsewhere. BLEEX is a solutions-driven project.

As the project investigator — Dr. Homayoon Kazerooni, Professor of Mechanical Engineering at the University of California at Berkeley — noted, the pool of potential beneficiaries of this research is immense.

Disaster rescue, firefighters and the victims and property they serve, as well as the disabled all stand to reap an untold value from this breed of exoskeleton and its incumbent technologies. As far as safety is concerned, if the exoskeleton fails for any reason, you can detach the robotic legs and continue with the backpack alone.

Guinan's Gag Goes Over Like a Lead Boilerplate

If it weren't published in the May issue, we might yell April Fool's over this one, have a good laugh, and be done with it. However, it was May, this is now June, and an unintentional joke — which we were not privy to — has been unleashed on us all.

By this writing, you may have already called us on this one. Three images — those of Boilerplate, the Steam Man, and the Automatic Man — that appeared with this column last month are all complete forgeries. These hoaxes were perpetrated by the man we now know to be a full-time comic book creator, part-time history fabricator, and 100% buffoon — Paul Guinan.

Seriously, this man provided these images as genuine, knowing we were writing a true history of ancient robotics.

Having intertwined history and hallucination so well — which he has apparently wasted much of his life on — he was able to dupe us momentarily.

Resources

1. Berkeley Human Engineering Lab: **www.me.berkeley.edu/hel**

2. The BLEEX Project: **http://bleex.me.berkeley.edu/hel/bleex.htm**

3. Cyborg Research – Electronics and Live Cells Combined: **www.berkeley.edu/news/media/releases/2003/06/09_toxic.shtml**

4. Cyborg Research 2: Bionic Chips, Live Cells and Circuitry: **www.berkeley.edu/news/berkeleyan/2000/03/01/bionic.html**

Image

Dr. Kazerooni believes it's important to change the image we have of exoskeletons from that which comic book characters, movies, and other sci-fi endeavors have given us. Exoskeletons are not powered body armor created to enable super soldiers, super heroes, or villains to break down doors and walls and kill people.

An exoskeleton in real world engineering is a robotic device used to aid people in moving and maneuvering heavy objects and payloads. The goal is for it to be a helpful, friendly, and transparent tool.

Though some might suspect DARPA's role (the Defense Advanced Research Project Agency) as being one of investing in the hopes of a day of super soldiers, the goal is actually to improve safety and efficiency of soldiers and other users.

Though many engineers worldwide are working on exoskeletons, this model is the only one where the pilot can actually put it on and walk a figure eight with it.

Dr. Kazerooni — the lead project investigator on the BLEEX project — would like us to know that he needs help from a variety of people, including those who work on sensors, servos, controls, code, and all sorts of things. Dr. Kazerooni is open to all kinds of input.

The work with the exoskeleton class of robots is still in its infancy. Dr. Kazerooni hopes that many others will come to work on exoskeletons in the near future and help to make his and other exos better, improving performance.

The BLEEX is an excellent example of the technology being developed for Tetsujin 2004. See pages 4 and 5 to learn more details about SERVO Magazine's powered, articulated exoskeletion competition, which will be held on October 21-23 in Santa Clara, CA in conjunction with RoboNexus. **SV**

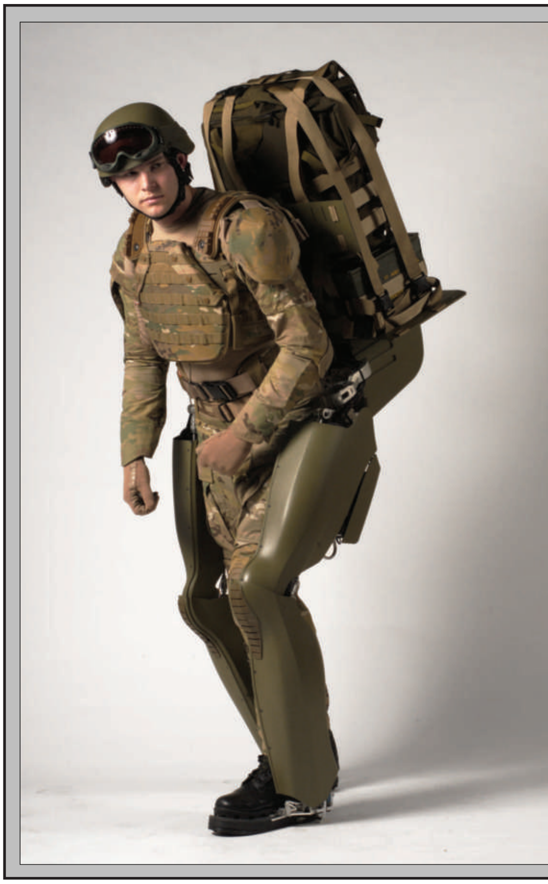


Photo courtesy of Homayoon Kazerooni, UC Berkeley.

Lessons From BLEEX for Your Own Exoskeleton Project

The BLEEX approach to electronics is unique in that inventors pieced together a local area network on the body, refered to as a BodyLAN. Instead of computers, this LAN connects small sensors and actuators that communicate with each other and the computer brain that runs the algorithm.

Benefits of this approach include easy upgrades with new sensor technologies that can be plugged in without making other changes.

Additionally, there is only one wire —instead of many — to each device on the BodyLAN.

Specifically, the BodyLAN uses high-speed, synchronous ring topologies. That helps explain how this all can be enabled with one wire (per ring). There are several modules on a ring, each of which communicates with the actuators and sensors closest to it. There are three rings. One for each of the legs and one for a Graphical User Interface (GUI) or other equipment, as needed.

The software or control algorithm is unique in its complexity and achievements. The software circles the ring topology and instead of taking direct input from the pilot (the wearer) it takes it from the exoskeleton, which provides input based on the data collected from the sensors.

The degree of decision-making the exo does on its own based on this input is as remarkable as how it is able to help the wearer.

The only machines that can move independently for any length of time use gas-driven engines. The BLEEX exoskeleton is also a gas-driven mobile platform. Batteries don't provide the energy or power density required. The result is the first field refuelable robot.

This small, hybrid, gas-powered engine drives the hydraulics that move the legs and also powers the computer.

The architecture of the robot provides a degree of freedom for the pilot that is unique. That the robot can aid movement and take over a hundred pounds off the person and still allow the person to reside within it and to have freedom of movement is amazing.

Robotics Resources

Movers and Shakers of the Robotic World

by Gordon McComb

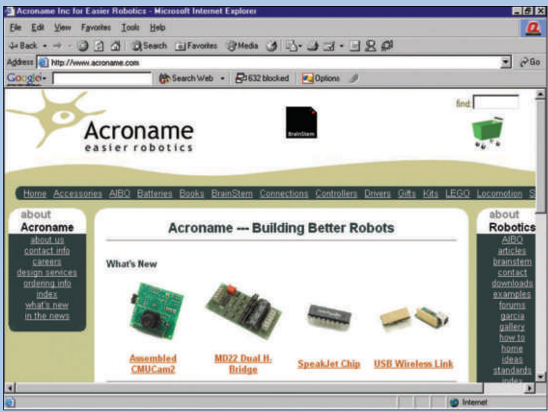
Movers and shakers are people, companies, or organizations that make significant contributions to a technology. SERVO Magazine *is a good example of a mover and shaker. Each month, this publication surveys the ever expanding landscape of personal robotics and brings the best news, how-to projects, and other robotics resources to you.*

Of course, SERVO *doesn't stand alone; there are a number of other movers and shakers in the personal robotics field and I dedicate this month's column to them. These are companies and non-profit organizations that have been advancing robotics for at least the past five years — many have been around for more than 10 years, having literally started with only a cockeyed dream and some extra space in the garage.*

Rather than try to list all of the companies and organizations I think are worthy of special attention, I decided to concentrate on just a handful for this month. I plan on revisiting this topic in future columns, covering additional leaders in the personal robotics field.

Readers, feel free to recommend your favorite mover and shaker. Write to me at robots@robotoid.com and let me know who you'd nominate to the Robotics Hall of Fame. What I'm looking for are companies or organizations that have been around for at least five years, and have made a significant contribution, directly or indirectly, to the art and science of personal robotics.

Acroname
www.acroname.com



Acroname is known for its wide selection of robotics kits and parts, as well as their in-depth application notes. The company is often among the first to import a new and exciting product directly applicable to personal robotics. In some cases, they serve as the US distributor of these products to other resellers. Acroname was among the first to offer the Sharp infrared distance sensors, for example. They are also a key source for the omnidirectional roller wheels made by North American Roller Products, the Devantech line of ultrasonic sensors, the CMUCam, and the Palm Pilot Robot Kit (PPRK).

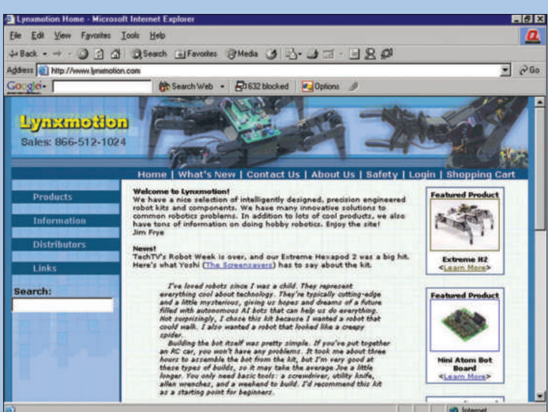
As noted above, the Acroname site is home to numerous application notes on using the various sensors, microcontrollers, and parts that the company offers. Additional resources for all products are noted at the bottom of the catalog listing. At the very least, most products include a link to the manufacturer's datasheet and many also include schematics, pinout data, programming notes, and hookup instructions. A fairly active online forum is also available and customers and others can send in their robots for inclusion in the Gallery pages.

Dallas Personal Robotics Group
www.dprg.org

The Dallas Personal Robotics Group (DPRG) is the kind of robotics club everyone wants in their home town. This group has weekly and monthly meetings, hosts regular robotics contests and challenges, provides in-depth instructional articles on its website, and maintains a very active (and vocal!) mail list. The mix of personalities, abundance of free advice, and combined know-how make the DPRG a unique contributor to personal robotics. The meetings (and even barbecues!) are local to Dallas area residents, but the web page and mailing list are available internationally.

The DPRG, which celebrates its 20th anniversary this year, also sponsors the well-received RoboRama competitions. Events include line following, sumo, fire fighting, something called can-can (push a can around — it's harder than it sounds), and several others. Regular events for the local members include Robot Builder's Night Out meetings on Tuesday and Wednesday of each week. The main RBNO happens Tuesday evenings at the DPRG headquarters building in Garland (North Dallas, TX) and includes dinner. RBNO West is on Wednesday evenings in Grand Prairie, TX.

Lynxmotion
www.lynxmotion.com



It's nearly impossible to visit any robot club meeting or competition without seeing at least one product from Lynxmotion. This company — founded in 1995 by robot enthusiast Jim Frye — provides a variety of top-notch kits and parts to the robotics hobbyist. The typical robot kit consists of laser cut Lexan (polycarbonate) plastic, servo or DC gear motors, and hardware. Construction manuals — available on the website — provide step-by-step details on building the kit. Kit options include control electronics, batteries, recharger, and various sensors, if applicable.

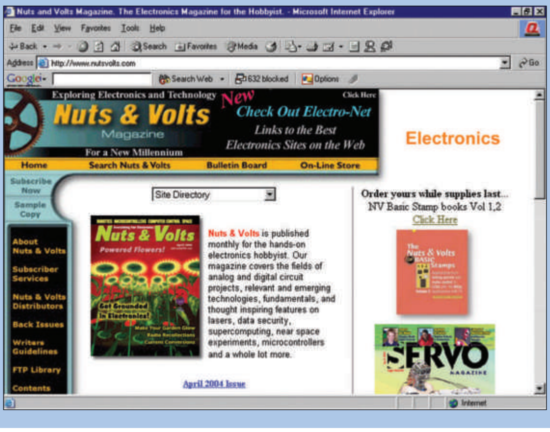
Until somewhat recently, Lynxmotion used a distinctive bright yellow plastic for its kits, but has since changed to clear or black polycarbonate. Lynxmotion is perhaps best known for two classes of robots: the six-legged walker and R/C servo-operated stationary arms. Walkers with 3, 12, and 18 servos are available, with prices from $99.00 for a hardware-only three-servo version. The stationary arms, which can also be attached to mobile platforms, provide four or five degrees of freedom. They're popular in schools for teaching the fundamentals of robotics and motion control. Other product categories include wheeled robots, such as standard-size sumo.

Netmedia BasicX
www.basicx.com

Netmedia is the parent company to the BasicX line of microcontrollers and small robot platforms. The BasicX (they have three versions) is a general purpose microcontroller, but its features make it ideally suited for robotics. It's not uncommon to find home brew robots designed around the BasicX. The most popular version of the BasicX seems to be the BX-24, a controller mounted on a 24-pin carrier. The BX-24 boasts pin-for-pin compatibility with the ever-popular BASIC Stamp BS2, though, naturally, chip programming is completely different. The BX-35 is a 40-pin DIP (or 44-pin TQFP) chip that is similar in programming to the BX-24, but offers more I/O pins. Both the BX-24 and BX-35 are based on Atmel AVR microcontrollers.

Somewhat new to the BasicX line is the XbotX Scout robot — a nifty, preassembled desktop robot that uses the BX-24 for a central brain. The XbotX Scout consists of two high torque GWS servos, custom injection molded rubber-rimmed wheels, plastic body panels, and an integrated circuit board that combines controller, back lighted LCD display, speaker, sensors, and pushbuttons — in other words, just about everything you need to get started. I've been playing with the XbotX Scout for a while and it's one of the most robust learning platforms I've found.

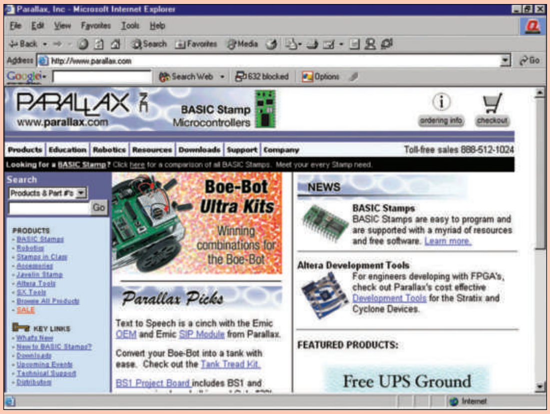
Nuts & Volts
www.nutsvolts.com



No mention of movers and shakers in the world of personal robotics would be complete without *Nuts & Volts Magazine*, the sister publication to *SERVO*. For over two decades, *N & V* has provided timely articles on all facets of electronics. Even before personal robotics became fashionable (again), *N & V* was at the forefront with regular features and a monthly column on amateur robotics. Many *SERVO* readers are already familiar with *Nuts & Volts*, but, if you're not, you owe it to yourself to check out the latest issue. Many newsstands, bookstores, and electronics stores also carry the magazine.

Also of interest to robot builders who use the Parallax BASIC Stamp is the four volume set of books of past "Stamp Applications" columns from *Nuts & Volts*. These columns have been penned by Stamp gurus Scott Edwards, Lon Glazner, and Jon Williams; many are either directly related to a robotics application or are readily adaptable. These books and many others can be ordered from the website.

Parallax
www.parallax.com



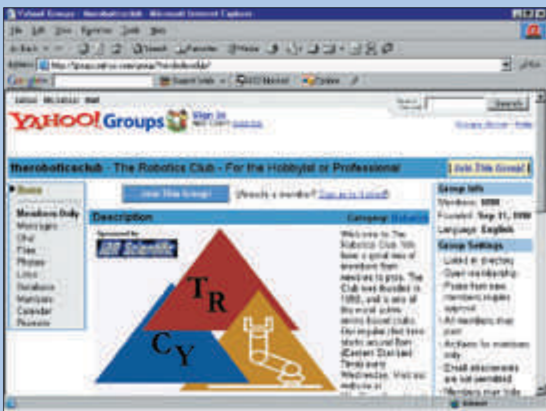
Parallax was not the first company to mount a programmable microcontroller on a carrier board, but, thanks to their marketing and a loyal following, their BASIC Stamp product soon became a de facto standard in the electronics world, particularly for hobby and educational robotics. Rather than trying to stuff a PC motherboard or the main board from a VIC-20 on a robot, builders were turning to the BASIC Stamp and its easy-to-learn Basic language programming to endow their creations with intelligence. I wouldn't venture a guess as to the number of robots that use a BASIC Stamp, but I imagine it's well into the hundreds of thousands. That's a lot of bots!

Over the years, Parallax has introduced new members to the BASIC Stamp family, with the BS2 among the most popular. This microcontroller is mounted on a 24-pin carrier and is completely self-contained with memory for downloaded programs, an oscillator crystal, and a voltage regulator. Like most microcontrollers of its ilk, the BS2 is programmed from a PC; programming instructions are then downloaded from the PC and into the BS2, where they are stored until erased.

Parallax also offers a line of easy-to-build robot kits, all using the BASIC Stamp, of course. The BOE-Bot (BOE stands for Board

of Education) is a two-wheeled desktop rover and is popular in schools. It comes with a set of experiments and expertly written documentation. Other kits include the Toddler (two-legged walker), a mini-sumo, and an aluminum, six-legged hexapod.

The Robotics Club of Yahoo
groups.yahoo.com/group/theroboticsclub



There are no local meetings of The Robotics Club of Yahoo — otherwise known as TRCY — but the group boasts a membership roster of nearly 2,000 — among the largest of any Internet-based robotics groups. TRCY "meets" on Yahoo Groups; you can join at no cost if you have a Yahoo username (that's free, too).

The main attraction of TRCY is the mail list. Once you join the group, you can elect to receive the TRCY mail list via Email or (like I do) you can read messages online. If you see a message you'd like to respond to, you can hit the Reply button and provide a response. Settings by the administrators of the group keep spam and off-topic postings to a minimum. New members are vetted, so if you'd like to post a message, it must be approved by an administrator. Once you become an old hand, your messages are posted without moderation.

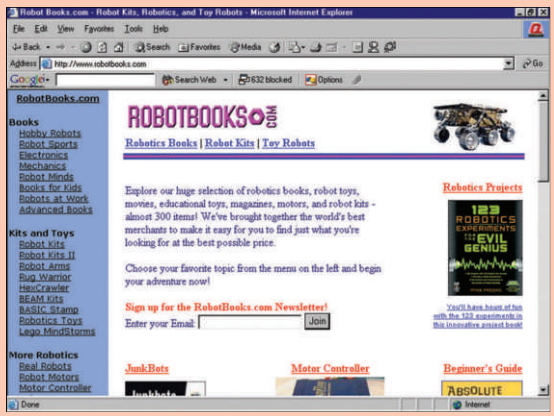
On Monday nights, you can join a lively chat discussion. Uploads to the Files section provide a way for members to share pictures of their robots and sample programming code. If you join just one Internet-based discussion group, consider this one at the top of your list.

Robotbooks.com
www.robotbooks.com

Robotbooks.com has become one of the most popular web destinations for personal robotics. In fact, Google.com ranks the website — a measure of its relevancy and popularity — at 8 out of 10. To put this into perspective, Microsoft.com is rated at nine out of 10.

Like their name suggests, Robotbooks.com offers books for sale, as well as other robotics-related products. These include kits, toys, and LEGO Mindstorms. With only a few exceptions, Robotbooks.com does not sell directly. Rather, when you buy from them, you're really buying from an affiliated online store. For books, the site uses Amazon.com, which almost everyone is already familiar with. Many of the kits and toys are provided through either Amazon or Hobbytron, another major online retailer.

You'll want to sign up for the free monthly newsletter, which is Emailed to you. The newsletter provides short descriptions of new books and other products that have been added to the site. The newsletter is a great way to keep up to date on the field of personal robotics.

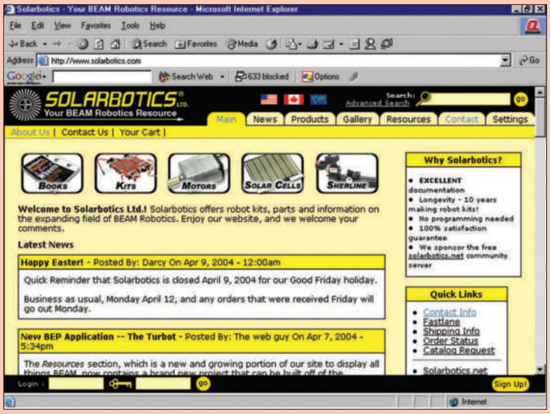


RobotStore.com
www.robotstore.com

Robotstore.com is the superstore of hobby and educational robotics. Theirs is perhaps the largest selection of robotics-centered products available — from books to kits to motors to individual parts. The site sells both their own in-house products and they act as resellers for other companies, such as Parallax and LEGO. Among their line is RoboBRiX, a series of interconnecting modules that each perform a specific task. The company also sells the Octobot Survivor, a self-learning desktop robot that is powered by solar energy.

Among the best known products from RobotStore.com is the Muscle Wire kits, put out by RobotStore's parent company, Mondo-Tronics. Muscle Wires are strands of shape memory alloy that contract when an electric current is applied. The wire relaxes to its original shape when current is removed (or, more accurately, when the wire cools down). Muscle Wire kits include flapping butterfly wings and an R & D kit for self experimentation. You can browse the company's wares online or ask for a printed catalog.

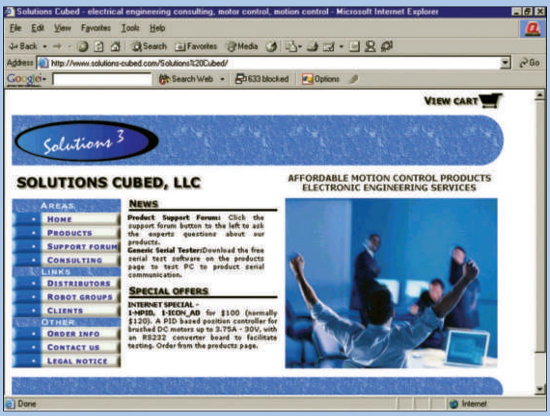
Solarbotics
www.solarbotics.com



Solarbotics is not the only source for BEAM robotics, but it's arguably one of the longest standing and most popular. This firm, based in Canada, was established a decade ago by owner Dave Hrynkiw and offers a wide variety of low cost kits and parts needed for building small robots. Their popular kits include a mini sumo, solar powered photo-sensitive crawlers (Photopopper and others), and the ScoutWalker — a small walking robot reminiscent of a daddy long legs.

Of particular interest is a series of low cost, Chinese made gear motors that were originally designed for small toys. These "GM" motors come in various sizes and gear reductions. They are used in a number of Solarbotics kits. The motors use a unique, double-flatted shaft, but Solarbotics also provides custom-made wheels made just for these shafts. The GM motors and wheels are enjoy enough popularity to also be resold by numerous other online retailers in the US and elsewhere.

Solutions Cubed
www.solutions-cubed.com



Yet another robotics-related company celebrating 10 years in the biz is Solutions Cubed. One of the first of their products I tried was the Motor Mind B ($25.00), an all-in-one motor controller with built-in PID feedback, tachometer input, and H-bridge. I've used several in small robot and automation designs over the years. Solutions Cubed has expanded on the concept and now offers the Motor Mind C (a higher capacity and two motors), as well as the ICON series of modules — which includes separate modules for an H-bridge, interface, and PID controller.

The company sells a variety of related products useful in robotics, including a nifty motor and wheel combination that also includes a mounting bracket. The motor is 200 RPM and operates from 4.5 to 18 volts (nominal 12 V DC). The wide foam wheel includes a hub that fits securely over the shaft of the motor with a locking set screw. The included wheel mount can be fastened to any robot base. Company president Lon Glazner contributed numerous BASIC Stamp columns in *Nuts & Volts Magazine* and many of their products offer quick interfacing to the Stamp line.

Honorable Mentions

Space doesn't allow me to include every notable mover and shaker, so, for this column, I'll just include some additional resources as honorable mentions and list them and others in more detail at a later date. Many of these companies or groups have been around for 10 years or more and a few — like Scott Edwards Electronics and the Seattle Robotics Society — were founders of the modern-day personal robotics movement.

All Electronics — **www.allelectronics.com**
Jameco — **www.jameco.com**
Scott Edwards Electronics — **www.seetron.com**
Seattle Robotics Society — **www.seattlerobotics.org**
Digi-Key — **www.digikey.com**
Portland Area Robotics Society (PARTS) — **www.portlandrobotics.org**
Technological Arts — **www.technologicalarts.com** SV

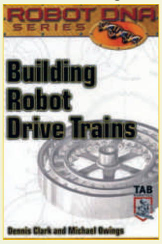
About the Author

Gordon McComb is the author of the best selling *Robot Builder's Bonanza*, as well as *Robot Builder's Sourcebook* and *Constructing Robot Bases*, all from Tab/McGraw-Hill. In addition to writing books, he operates a small manufacturing company dedicated to low-cost amateur robotics. You're welcome to visit at **www.budgetrobotics.com** He can also be reached at robots@robotoid.com

Mind Candy For Today's Roboticist

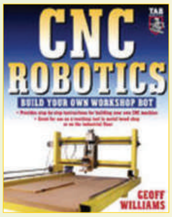
The *SERVO* Bookstore

Building Robot Drive Trains
by Dennis Clark / Michael Owings



This essential title in McGraw-Hill's *Robot DNA Series* is just what robotics hobbyists need to build an effective drive train using inexpensive, off-the-shelf parts. Leaving heavy-duty "tech speak" behind, the authors focus on the actual concepts and applications necessary to build — and understand — these critical, force-conveying systems. **$24.95**

CNC Robotics
by Geoff Williams



Now, for the first time, you can get complete directions for building a CNC workshop bot for a total cost of around $1,500.00. *CNC Robotics* gives you step-by-step, illustrated directions for designing, constructing, and testing a fully functional CNC robot that saves you 80 percent of the price of an off-the-shelf bot and can be customized to suit your purposes exactly, because you designed it. **$34.95**

PIC Robotics: A Beginner's Guide to Robotics Projects Using the PIC Micro
by John Iovine

Here's everything the robotics hobbyist needs to harness the power of the PICMicro MCU! In this heavily-illustrated resource, the author provides plans and complete parts lists for 11 easy-to-build robots — each with a PICMicro brain. The expertly written coverage of the PIC Basic Computer makes programming a snap — and lots of fun. **$19.95**

Robots, Androids, and Animatrons, Second Edition
by John Iovine

There's never been a better time to explore the world of the nearly human. You get everything you need to create 12 exciting robotic projects using off-the-shelf products and workshop-built devices, including a complete parts list. Also ideal for anyone interested in electronic and motion control, this cult classic gives you the building blocks you need to go practically anywhere in robotics. **$19.95**

Robot Mechanisms and Mechanical Devices Illustrated
by Paul Sandin

Both hobbyists and professionals will treasure this unique and distinctive sourcebook — the most thorough — and thoroughly explained — compendium of robot mechanisms and devices ever assembled. Written and illustrated specifically for people fascinated with mobile robots, *Robot Mechanisms and Mechanical Devices Illustrated* offers a one-stop source of everything needed for the mechanical design of state-of-the-art mobile 'bots. **$39.95**

Robot Builder's Bonanza
by Gordon McComb

Robot Builder's Bonanza is a major revision of the bestselling bible of amateur robot building — packed with the latest in servo motor technology, microcontrolled robots, remote control, LEGO Mindstorms Kits, and other commercial kits. It gives electronics hobbyists fully illustrated plans for 11 complete robots, as well as all-new coverage of Robotix-based robots, LEGO Technic-based robots, Functionoids with LEGO Mindstorms, and location and motorized systems with servo motors. **$24.95**

Robot Builder's Sourcebook
by Gordon McComb

Fascinated by the world of robotics, but don't know how to tap into the incredible amount of information available on the subject? Clueless as to locating specific information on robotics? Want the names, addresses, phone numbers, and websites of companies that can supply the exact part, plan, kit, building material, programming language, operating system, computer system, or publication you've been searching for? Turn to the *Robot Builder's Sourcebook* — a unique clearinghouse of information that will open 2,500+ new doors and spark almost as many new ideas. **$24.95**

We accept VISA, MC, AMEX, and DISCOVER
Prices do not include shipping and may be subject to change.

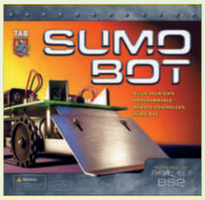
Designing Autonomous Mobile Robots
by John Holland

Designing Autonomous Mobile Robots introduces the reader to the fundamental concepts of this complex field. The author addresses all the pertinent topics of the electronic hardware and software of mobile robot design, with particular emphasis on the more difficult problems of control, navigation, and sensor interfacing. Its state-of-the-art treatment of core concepts in mobile robotics helps and challenges readers to explore new avenues in this exciting field. The accompanying CD-ROM provides software routines for the examples cited, as well as an electronic version of the text. **$49.95**

The Ultimate Palm Robot
by Kevin Mukhar / Dave Johnson

Originally developed by Carnegie-Mellon University robotics department graduate students, this prototype has enjoyed a cult following among enthusiasts. Using software provided by the authors and this step-by-step guide, you can build and operate your own version of the same robot. Learn about parts, software, programming, games, robot resources, and much more from this exciting, one stop guide to Palm robots. **$29.99**

SUMO BOT
by Myke Predko / Ben Wirz



Here's a fun and affordable way for hobbyists to take their robot building skills to the next level and be part of the hottest new craze in amateur robotics: Sumo competition.

Great for ages 14+, the kit comes complete with:

- Pre-assembled PCB
- Multi-function, dual-channel remote control
- Robot hardware, including collision-sensing infrared LED and receivers
- CD-ROM with programming instructions and file chapters of robot building tips and tricks
- A built-in Parallax BASIC Stamp 2 and prototyping area, allowing hobbyists to create their own robot applications without having to purchase additional Parallax products **$99.95**

BIO-FEEDBACK

Continued from Page 9

Dear SERVO:

Does the magazine have any interest in the field of model or toy robotics or is it strictly a magazine on how to build real, working robots?

Anonymous
via Internet

We aim for a balanced mix of both types of articles. — Editor Dan

Dear SERVO:

In today's mail, I received a foldover card advertisement for your magazine. Unsure as to its nature, I visited your website and some memories flooded back.

I retired at the end of 1994 from a career as a consultant electronics engineer, one who had played a part in the budding technology of robotics, although my main concern had been automatic test systems for electronics manufacturers.

Among things other than ATE, I once set up a classic Lionel O-gauge train to run on a servo that controlled its velocity (in either direction) to four decimal places and its position to within a thousandth of an inch. This is the closest I ever came to using the technology as might a hobbyist, but, in this case, it was as a trade-show demonstrator.

I used a pulse-width modulation system on that servo. I am the holder of the patent for the Crydom Series 1-DC solid-state relays, devices vital to many industrial robots.

These days, I write fiction, and I wish for your readers to have fun with their hobbies (or jobs!). Best wishes to all.

Kenneth H. Fleischer
via Internet

Dear SERVO:

I really would like to see more complete projects in later issues. The May one had the Athena Bot, which I plan on building, but the only full robots have been the C. E. project, the Soz Bot, and the Athena Bot.

I really like the eight-part articles like C. E.; maybe you could do one on a CNC machine. I do find the rest of the magazine interesting and educational, but I expected more projects when I subscribed. Keep up the great work.

Anonymous
via Internet

Verly Flores from Tensilica shows off the May issue of *SERVO* at the Embedded Systems Conference in San Francisco, CA.

Live From Frederick Mission Control

by Joan Horvath

Your average Mission Control is a gleaming room with lots of screens and people milling about, shuffling papers. People talk to each other in tense language: "Flight: Control." "Go ahead, Control." It's drama. It's *The Right Stuff*. It is, after all, rocket science.

These scenes were always set in Houston, TX or — if one wants to step over to robots rather than astronauts — in Pasadena, CA. I've been there and done that (in Pasadena, anyway), but not any more. The action is now in Frederick, OK; come on down for a visit and start building flight hardware (and have some pretty good pecan pie).

Lately, the US has not had the ability to send anyone into orbit. The shuttle is grounded and American astronauts are reduced to hitching rides on any Russian taxi going their way. How did we get here and what can we do about it? Can the Average Garage Rocket Inventor bail NASA out? Can small farmland towns decide that they want to talk to the Federal Aviation Administration about becoming a spaceport?

Amazingly (frighteningly?), this is just what is starting to happen. For many years, there has been a small group of wildly underfunded folks trying to build The Rocket That Will Change Everything. Space flight has been pretty limited for a long time just because it's so incredibly expensive. Entrepreneurs in the space industry are fond of wistfully pointing out that space is only 100 miles away and it should not cost $500,000,000.00 each time we want to go, but what are the alternatives?

Well, first of all, there's working with the Russians. Ironically, some time ago — just because they were so strapped for cash — the Russians restructured their space program and started looking for paying customers to subsidize the science — space tourists, advertisers, you name it. They've kept themselves afloat that way, in part because of American entrepreneurial companies that arrange for rides to space on Russian vehicles for millionaires. It's been said that folks on Capitol Hill should hire Russian consultants on how to be space capitalists; it's hard to imagine any situation more ironic, particularly given the Cold War missile heritage of space hardware.

Suppose you prefer a more hands-on approach and want to actually build some spaceships? What then? Well, today, there is almost an astounding assortment of options. (If you want to get paid, the options are significantly less abundant, but *SERVO* is, after all, a hobbyist magazine.) Your choices fall into two major categories: this might work and these guys are nuts.

Given the combination of explosives, entrepreneurs, and grand intentions, the latter contingent is probably not hard to imagine. Many in this class are very proud that they have no formal training in aerospace engineering; in some cases, one wonders if it might be even more dangerous if they did.

Moving on to the this might work group: there's a $10 million prize (the X-Prize) for the first group to take three people up to 100 kilometers altitude, bring them back safely, and do it all again in two weeks or less, while changing out less than 10% of the vehicle's mass (excluding fuel).

Oh, by the way, you have to do all that by New Year's Day, 2005, when the prize money (funded by an insurance policy that bets the prize won't be won) disappears forever. Over two dozen companies are chasing this worldwide, so you'd better hurry up if you want to compete. (By the way, Paul Allen — the cofounder of Microsoft — is funding one contender, so you'd better work on fattening up the ol' piggy bank, too.)

So you don't think you can quite get it together for the X-Prize? What then? Well, have we got a deal for you! You can join forces with the Global Space League, based in Frederick, OK (**www.globalspaceleague.org**).

Here's a bit of background on the group: Before becoming addicted to starting companies, I spent 16 years at JPL, NASA's Jet Propulsion Laboratory, famous these days for producing Mars Rovers. While there, I observed an interesting public relations paradox: People really, really like to be in the presence of flight hardware before it goes somewhere, but the nature of the beast means that people are rarely allowed to do that.

To try and do the next best thing, I put together a program at JPL that allowed toy and entertainment companies to cut deals to have JPL'ers

help them make very accurate spacecraft toys, television shows, and so on. In 2000, I spun this program out into my first company — Takeoff Technologies **www.takeofftech.com**) — and various space entrepreneurs started calling and asking me to cut similar deals for them.

Now, of course, many of them were offering, say, eventual rides on their vehicle(s) as payment for my services, with no comprehension about why cash up front would be preferable. Alternately, they had spent and planned to spend all their waking hours in the middle of deserts firing things upward. Why multimillion dollar sponsorship deals were not likely to be immediately possible was incomprehensible. They didn't understand that sponsors were more interested in selling to males, aged 18-45, than to space enthusiasts in the desert.

"It's cool!" they would say. "But no one can see it," I would reply. "Oooohhhh ..." Many of these entrepreneurs were scratching along, raising a few thousand here and a few there, if that. It was clear that something had to be done to let those with real promise get started.

So, the concept of Global Space League was born (now formalized into an Oklahoma nonprofit educational and scientific corporation). The town of Frederick offered us an early home — a well-kept airport — and enthusiastic fund raising assistance, so we have been rounding up early-stage flight entrepreneurs to come down and fly.

We ask our subscribers and participants in our events (aimed at students from kindergarten through grad school) to compete to build an experiment to fly on these new vehicles. Sponsors and subscription fees cover the costs of the flights. We let entrepreneurs who might not have 100% of the technical skills they need collaborate with universities or others who just might be able to provide the same. **SV**

Author Bio

Joan Horvath splits her time between the culinary delights of Pomona, CA (close to Pasadena) and Frederick, OK. She is the co-founder of both Takeoff Technologies, LLC and Global Space League, Inc. She also works for the town of Frederick to diversify their economy by growing their technology business base. Her work was recently published in *Scientific American.*

Advertiser Index


Move over, Rover!
Whether you're heading to Mars or your own backyard, the Tank Tread Kit adds a whole new dimension to your Boe-Bot™ Robot.
By securing 2 metal plates to the side of your favorite robot, it's ready to be converted using a set of plastic gears and treads. With this latest add-on, you can even roll over rocks!
The parts kit includes everything you need to make the change from wheels to treads. Standard source code as featured in the Robotics with the Boe-Bot text is compatible with the Tank Tread Kit.
$34.95
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